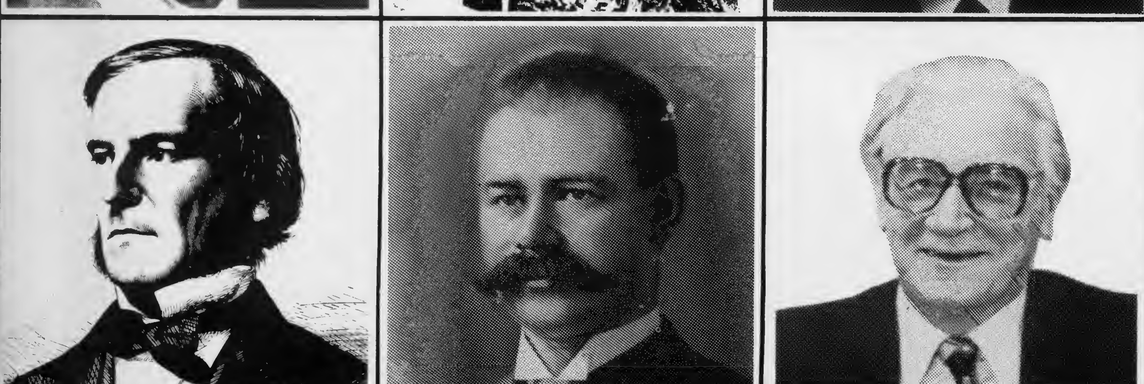
# *THE HISTORY OF* COMPUTING

***A Biographical Portrait of the Visionaries Who Shaped the Destiny of the Computer Industry***




***By***
***Marguerite Zientara***
***Computerworld***
***Writer/Analyst***

*Who were the men and women who shaped our destiny by daring to believe in the impossible — in the ability of a machine to assume the tedious human function of arithmetic calculation — and free our minds for more rewarding endeavors?*

*Computerworld's 12-part "History of Computing" is a probing series that attempts to answer that question by explaining the social, political and practical forces that shaped the lives of those visionaries of calculation and computing.*

*Researched and written by CW Writer/Analyst Marguerite Zientara, the series begins with a look at Blaise Pascal and the historical developments that preceded his accomplishments. The series concludes with a glimpse into the future of the technology, examines some possible social effects of that technology and poses some questions — the answers to which only time will tell.*

Ms. Zientara wishes to express her appreciation to Brad Schultz, senior editor, Computerworld, and Elmar Elmauer, senior editor, Computerwoche, for their contribution to the series, a joint interview with Konrad Zuse (Pt. 9).

# Part 1 . . . The Life Of Blaise Pascal

*Truth is so obscure in these times, and falsehood so established, that unless we love the truth, we cannot know it.*

— Blaise Pascal, *Pensees*

Under the shadow of a long-ago bloody war was born the man who would successfully design and build the first workable, automatic calculating machine — mankind's first baby step toward the electronic digital computer of today.

The year was 1623 and the war was Europe's Thirty Years' War, fought between the newly declared Protestants and hard-line Roman Catholics. Then in its fifth year, the conflict was to last another quarter-century after the birth of Blaise Pascal, the French scientist and philosopher whose mathematical and spiritual contributions would influence the world at least as much as did the conflagration that greeted his arrival.

Recognized today as one of the most eminent physicists and mathematicians of his time — having developed the theory of probability — as well as one of the greatest mystical writers in Christian literature, Pascal is best known to modern data processors as the developer of the first calculator.

Blaise Pascal was born in Clermont-Ferrand, one of three surviving children of Etienne Pascal, the prominent second president of the Court of Aides at Clermont, and his wife, Antoinette Begone. Blaise's grandfather, Martin Pascal, was the treasurer of France.

While Blaise's social position may have been guaranteed by birth, his health and survival were not. At the age of one, he became seriously ill with either tuberculosis or rickets and reportedly suffered some accompanying emotional problems as well.

Doctors found that the sight of water made him hysterical and he is said to have thrown frequent tantrums upon seeing his father and mother together. After an ill-fated attempt to cure his "sorcerer's spell" through witchcraft, time was allowed to heal the child to a full recovery, although ill-health was to plague him all his life.

When Blaise was four, his mother died, leaving her husband lonely and disconsolate. Etienne Pascal reacted by turning from his work and gradually assuming the full responsibility for his children's education.

In 1631, Etienne sold his post to a brother, transferred most of his property into government bonds and moved to Paris with his son and two daughters. There, the studies continued that were to lead Blaise to his prodigious accomplishments in physics and mathematics. Under the tutelage of his father — a talented mathematician in his own right — Blaise was taught to learn the purpose of a fact and its value before proceeding, or to "keep the boy superior to his tasks," in the words of his older sister.

Showing his genius early, Pascal at 11 conducted experiments and then wrote a paper on the cessation of sounds when vibrating objects are touched. While the child's natural curiosity drew him closer and closer to the subject of geometry, his father's unorthodox teaching methods called for the study of Greek and Latin first.

Etienne Pascal reportedly went so far as to lock up all his mathematics textbooks and asked his own friends not to mention mathematics in the presence of his son. He did, however, give Blaise a definition of geometry as the science of making true diagrams and of finding the proportions between them.

Armed only with that definition, Blaise began drawing circles and lines, and writing down observations about their relationships. Without benefit of a teacher, young Blaise discovered for himself the basic axioms of geometry. Still without benefit of a teacher, young Blaise went even further and proved the 32nd proposition of Euclid — that the sum of the angles of a triangle is equal to two right angles.

No longer could his natural talent and proclivity be ignored. Overwhelmed, Blaise's father immediately undertook to enlighten his son on the mysteries of geometry. From that point on, Blaise's intellectual development skyrocketed. At the age of 12 he was appointed to a commission for judging procedures of determining longitudes; in the same year, he also uncovered an error in Rene Descartes' geometry. At the age of 13 he was introduced into the society of the Academie Libre, sitting in weekly to observe the brilliant French intellectuals of the day.

When Blaise was 16 the family's circumstances shifted somewhat in a fateful change that was to lead directly to Blaise's developing the automatic calculator.

The government bonds in which Etienne Pascal had invested most of his property suddenly lost value due to the French government's lowering the value of revenues in an effort to collect needed funds for itself. The resulting financial losses forced the family to move from Paris.

In Rouen, Etienne Pascal was appointed Royal Commissioner in High Normandy for the Tax Service, a post that called for monumental arithmetical calculations as part of his tax assessments.

While Blaise had been preparing to write a concise study of the entire field of mathematics, his father was now constantly requiring his assistance in the drudgery of hand totaling endless columns of numbers. The situation brought the young man's considerable problem-solving talents into play and he quickly realized the need for and possibilities of a mechanical calculating machine.

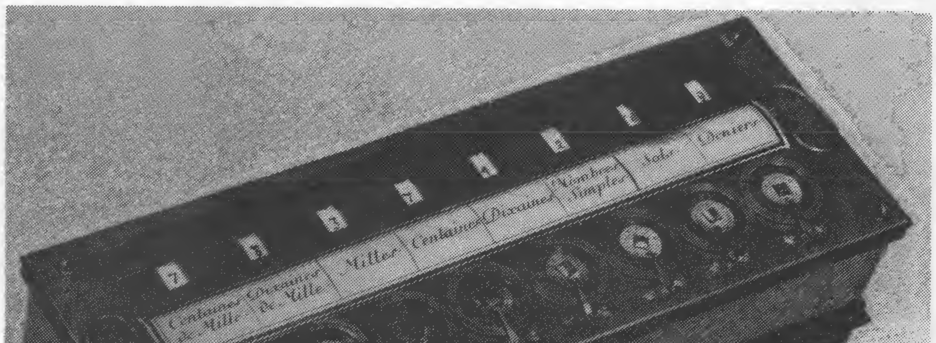
Although a number of men before him had attempted to make such a calculator, some got no further than written plans and some succeeded only to have the finished product destroyed, either by Nature or by human nature (see related story).

Blaise Pascal, however, only 19 when the concept formulated in his mind, worked and reworked various models of his calculator until he was nearly 30 — when he astounded all of Europe with his perfected, working model of an automatic, mechanical calculator.

The "pascaline," essentially like the calculators still in use only decades ago, arranged the digits of a number in wheels. When each wheel made a complete revolution, it would in turn shift its neighboring wheel one-tenth of a revolution, thereby totaling each digit counted. On the top of the box was a series of windows through which the totals could be read.

Although the machine incorporated eight movable dials, corresponding to the French system of currency at the time, calculations in the decimal system can be made by ignoring the two dials on the extreme right.

For example, to add 236 plus 422, one would first turn all the dials so that zeros appear in all the windows. Using the decimal system — starting with the third dial from the right — the user inserts a stylus into the slot marked 6, for units. The dial is then rotated clockwise until the stylus is stopped by a bar, as in dialing a telephone.



**The Pascaline** Photo Courtesy of IBM

The next dial on the left, for the tens, is revolved from 3 until it stops. Finally, the next dial to the left, representing hundreds, is turned from 2 until it stops. At this time, the numbers 236 appear in the windows reading left to right. Should 422 be added and the process repeated, the windows would read the total, 658.

In order to subtract, a flat metal ruler located just above the windows is pulled forward, uncovering a second set of windows that are extensions of the first set. To subtract the number 1 from 3, the user turns the dials until 3 appears in the window. After dialing 1, the remainder, 2, automatically appears on the indicator.

The pascaline came to fruition only after more than 50 models had been constructed, some made of wood, others of ivory, ebony and copper. At least 10 of these are still known to exist. Connecting rods, flat metal strips — both plane and curved — chains, cones and concentric and eccentric wheels were all used throughout the many attempts, which resulted finally in a lightweight polished brass box, about 14 in. by 5 in. by 3 in.

The machine, which could add and subtract only, was based on extremely precise interconnected gears. The most difficult mechanism to incorporate was the ratchet device that communicated by one revolution of one wheel a movement of one digit to the wheel of the next highest order.

Blaise's sister described the ratchet concept as "the foundation on which nearly all the calculating machines have since been constructed." Her words held true for more than 300 years.

*The arithmetical machine produces effects which approach nearer to thought than all the actions of animals. But it does nothing which would enable us to attribute will to it, as to the animals.*

— Pensees

"Will" or not, Pascal's accomplishment astonished all of Europe and won great acclaim for its inventor, although the great wealth he and his father assumed would follow never came. After all the years and large amounts of money that had been spent on developing the calculator, besides a widespread advertising campaign upon its completion, it was a complete failure in the business world.

Although Pascal had made the machine extremely simple to operate, potential buyers felt it was too complicated and could be repaired only by Pascal. In addition, many claimed that human labor was still less expensive than the calculator that would replace it.

Furthermore, the machine reportedly suffered from lack of positive action. The setting wheels could be turned in error part way between digit positions, rendering it less than completely accurate. There was also an element of fear — similar to the anxiety expressed today about computers — surrounding the machine: Would it lead to unemployment among bookkeepers and other types of clerks?

That question was not to be answered in Pascal's lifetime since, even though the machine was praised in prose and verse, it was not snapped up by buyers to become a best-selling commodity.

While wealth did not flow to the pascaline's maker, fame took his name outside the intellectual community and into the consciousness of the entire world, a world that Pascal was soon to renounce.

At the age of 30, his many scientific accomplishments behind him, Pascal was seized by "a great scorn of the world and an unbearable disgust for all people who are in it." He instructed his family to regard his scientific interests as "the games and diversions of his youth," his sister wrote.

*How wonderful it is that a thing so evident as the vanity of the world is so little known, that it is a strange and surprising thing to say that it is foolish to seek greatness.*

— Pensees

He devoted the remaining nine years of his life to God, wrote prolifically on spirituality and returned to science only briefly in an attempt to divert his mind from the intense pain of a serious toothache — one of several chronic physical ailments that had troubled him for more than a decade. For eight days, Pascal concentrated exlusively on mathematics and succeeded in solving many of the problems surrounding the geometry of the cycloid.

By 1658 his health was steadily deteriorating. Although he continued to write or dictate his religious observations, he was never again to return to mathematics.

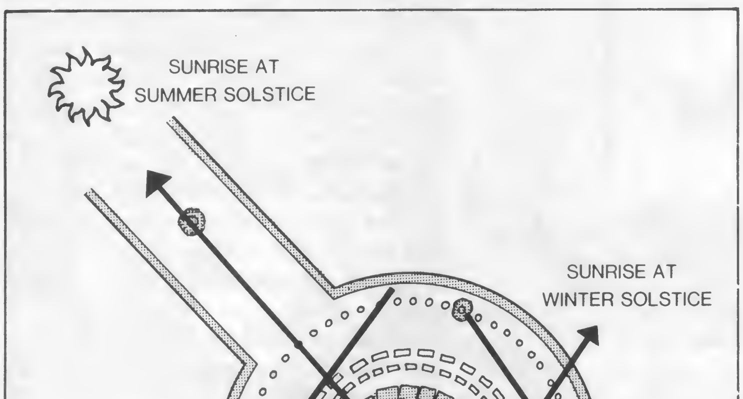
In 1662, at the age of 39, Blaise Pascal died of a brain hemorrhage. The great mathematician who buried his talents in deference to what he regarded as the real purpose of his life uttered his last words: "May God never abandon me!"

# 'Computers' Go Back at Least 5,000 Years

The Seventeenth Century was not, of course, the first time man had grappled with the problem of making fast, accurate numerical calculations, although it was a vigorous period for mathematics because of the boom in navigation and commerce.

The earliest known mechanical counting aid is the "dust abacus," traced back at least 5,000 years to the "cradle of civilization," the Tigris-Euphrates Valley in southwestern Asia. The dust abacus was nothing more than a dust- or sand-covered surface on which figures could be drawn with a stylus.

The abacus as we know it was invented in China in the second centu-




CW Drawing by H. Fling

**Diagram of the mysterious Stonehenge, considered by some to be an early astronomical calculator.**

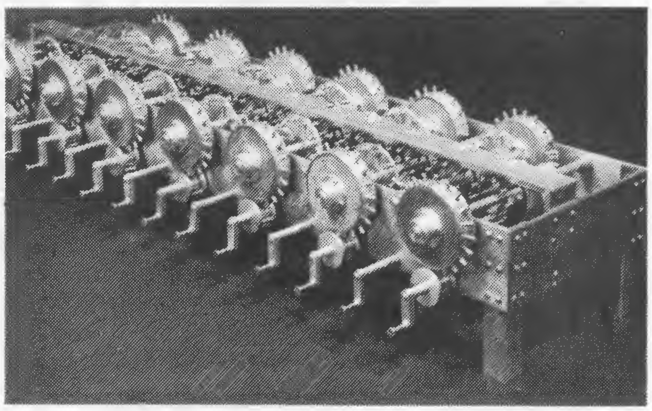
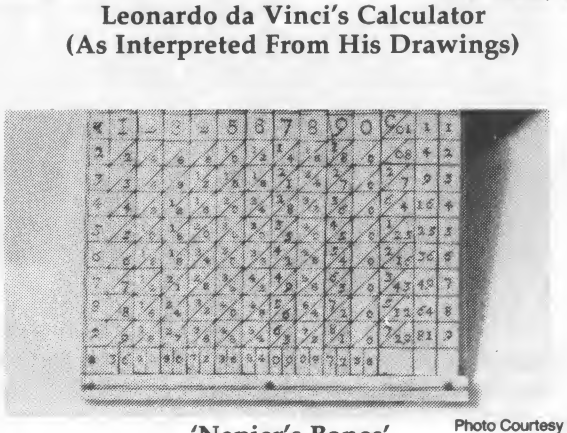


Photo Courtesy of IBM

**Leonardo da Vinci's Calculator (As Interpreted From His Drawings)**



**'Napier's Bones'**

Photo Courtesy of IBM

ry A.D. The Chinese version and the Japanese soroban — both extraordinarily fast — are still in use today.

Their efficiency was pointedly illustrated shortly after World War II, when Private T.N. Wood, the most skilled electric desk calculator operator with the American troops in Japan, pitted his talents against a Japanese soroban. Testing speed and accuracy against the soroban-wielding Kiyoshi Matsuzaki of Japan's Ministry of Postal Administration, America went down to dismal defeat.

In various forms, the abacus existed in all the civilizations of antiquity. In ancient Rome it was a grooved tablet while in China, Japan and Greece it remains as a frame with beads strung on parallel wires.

In medieval England, a simplified form of abacus comprised a tablet ruled into spaces representing the positions of the counters, while coins, buttons or other small objects were moved to make the calculations. The checkered tablecloth, from which the British Exchequer derives its name, was originally a calculating device of this nature.

Also in England, approximately 2,000 years before the Middle Ages began, Stonehenge was erected on Salisbury Plain. Comprised of concentric circles of massive stones and other landmarks, the monument has long puzzled archeologists.

Considered by some an early astronomical calculator, Stonehenge has been shown — with the help of computers — to indicate the solstices and beginnings of seasons, as well as predict eclipses of the sun and moon. The arrows drawn in the illustration show the alignment of landmarks (stones, pits and the circles' center) that pointed to the rising and setting of the sun on the days of the summer and winter solstices.

A later astronomical computer, this one mechanical, was recovered from a sunken ship off the coast of Greece in the 1930s and attributed to the first century B.C. The device contains carefully designed geartrains that evidently turned indicator hands on its front dials at speeds exactly analogous to those of planetary motions.

In the first century A.D., Gerbert of Aurillac — a French shepherd boy who would later become Pope Sylvester — made the first attempt in Western Europe to mechanize the abacus. Drawing on ideas he gleaned from the Moors, who then occupied Spain and Northern Africa, he spent many years trying to perfect his device, although it never worked accurately. He had 1,000 counters made of horn and arranged into 27 divisions. Since the concept of zero was hardly known at the time, his instrument proved to be not much better than hand operations.

There are reports of another Spaniard named Magnus who then took up the idea and around 1000 A.D. created a calculating machine of brass, in the shape of a human head, the figures of which appeared in the place of teeth. The priests of the day are said to have thought the device was something superhuman and smashed it with clubs, destroying all evidence of its accuracy.

The 1967 discovery of two bound volumes of Leonardo da Vinci's notebook materials in Madrid's National Library of Spain showed that the 15th century genius — never regarded as a contributor to the problems of calculation — did indeed address the question. His drawings describe a machine that would maintain a constant ratio of 10:1 in each of its 13 digit-registering wheels.

No working model is known to have existed and experts doubt Pascal ever saw da Vinci's sketches.

In 1614, John Napier, Baron of Merchiston in Scotland, discovered the logarithm, by which mathematicians could transform multiplication to addition and division to subtraction. Logarithmic tables remained the basis for lengthy computations until the early 20th century, when mechanical calculators came into their own.

Also developed by Napier was a device called "Napier's Bones," which amounted to a "lookup" table for multiplication. The "bones" were actually a movable multiplication table comprised of bone strips on which numbers were stamped. When placed into the proper combination, these strips could perform direct multiplication.

In 1623, the year Pascal was born, Wilhelm Schickard, a German professor of biblical languages and astronomy, designed a machine that reportedly could add, subtract, multiply and divide. Unfortunately, the model was destroyed in a fire and a new one was never built.

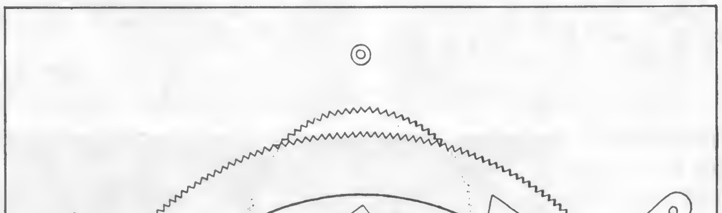



**Diagram of a First Century B.C. Astronomical Computer (From "An Ancient Greek Computer" by Derek J. de Solla Price. Copyright© June 1959 by Scientific American, Inc. All rights reserved.)**

*"It is unworthy of excellent men to lose hours like slaves in the labor of calculation which could safely be relegated to anyone else if machines were used."*
— Gottfried Wilhelm Leibniz

# Part 2 . . . The Leibniz Legacy

Developing a calculator that went beyond the capabilities of Blaise Pascal's and allowed the user not only to add and subtract, but to multiply, divide and extract square roots would have been an accomplishment worthy of any 17th century inventor's pride.

But to Gottfried Wilhelm Leibniz, one of the great universalists of all time, it was among the least of his contributions to the 17th century and to humanity in general.

The Leibniz legacy includes impressive discoveries and discussions in such diverse areas as natural philosophy, nautical science, optics, hydrostatics, mechanics and mathematics, as well as diplomatic accomplishments in his role as statesman.

Leibniz is also the one who evolved the well-known theorem of optimism: "Everything is for the best in this best of all possible worlds," later satirized by the French writer Voltaire in his novel *Candide*.

Born 23 years after Pascal, in 1646, yet into the same Thirty Years War, Leibniz undoubtedly felt more keenly the devastating effects of that conflict, since his homeland, Germany, was by far the hardest hit of all the countries involved.

In fact, the Treaty of Westphalia, marking the end of the war in 1648, ensured the emergence of Pascal's France as the chief power on the continent and disastrously retarded the political unification of Germany.

While Germany had previously been one of the most prosperous regions of Europe, historians estimate that no less than half the German populace perished during the war. Countless German cities, towns, vil-

Courtesy of Culver Pictures

Leibniz in Berlin, circa 1700

lages and farms were totally destroyed, and approximately two-thirds of the industrial, agricultural and commercial facilities were in ruin.

Religion no longer played a major role in German life, and education and other forms of intellectual activity came to a virtual standstill. Into such turmoil, on June 21, 1646, was born the genius who would help renew the culture of Germany.

The effects of the Thirty Years War notwithstanding, Leibniz was exposed to a scholarly environment early in life, as are so many young prodigies. The son of a professor of moral philosophy at the University of Leipzig, he had full access to his father's library as soon as he could read.

When Gottfried was six, his father died, but not before passing along his passion for history to his young son. Before the age of 10, Gottfried had consumed books on Cicero, Pliny, Herodotus, Xenophon and Plato.

Years later he acknowledged that the ancient writers had a great effect on his understanding of the world's knowledge. Early in life he established two rules for himself: definiteness and clarity of diction, and doing and saying everything for a purpose and toward an end.

These dicta were to lead him to the study of logic — one of his lifelong passions. He learned to use knowledge efficiently by classifying and systematizing it, by using signs and characters in place of words, by generalizing terms and by bringing every inquiry under a method and principle. Such methods eventually led to some of his greatest mathematical contributions.

Largely self-taught as a child, by age 15 he was ready to enter the University of Leipzig. Having studied Latin from the age of eight and Greek from the age of 12, Leibniz found classical studies no longer satisfied him and he turned to logic.

Although he entered the university as a student of law, Leibniz still found enough time to explore the writings of the modern or "natural" philosophers — Kepler, Galileo, Descartes and Lull. Seeing that this newer philosophy could be understood only by those acquainted with mathematics, Leibniz spent the summer of 1663 at the University of Jena, laying the mathematical groundwork that was to lead to many of his most profound discoveries.

Leibniz had earned his bachelor's degree that year at the age of 17 with a brilliant essay foreshadowing one of the primary doctrines of his mature philosophy, that of "the organism as a whole." It was during his years at the university that his mother died.

After his distinguished university career, in 1666, at the age of 20, he was fully prepared for his doctor's degree in law, but strangely enough was refused it by the faculty. The official reason given was his youth, but it is said that the faculty was jealous of the fact that Leibniz at 20 knew more about the law than all his teachers put together.

Disgusted with such petty behavior, Leibniz left his home in Leipzig for good and went to Nuremberg where the Affiliated University of Altdorf granted his doctor's degree later that year for his essay on a new (historical) method of teaching law. Not only did he earn his degree, but the university reportedly begged him to accept a professorship of law, an offer he refused for reasons unknown.

It was also in the year 1666 that Leibniz wrote what he later referred to as a "schoolboy's essay," *De arte combinatoria*, in which he tried to create "a general method in which all truths of the reason would be reduced to a kind of calculation. At the same time this would be a sort of universal language or script, but infinitely different from all those projected hitherto; for the symbols and even the words in it would direct the reason; and errors, except those of fact, would be mere mistakes in calculation."

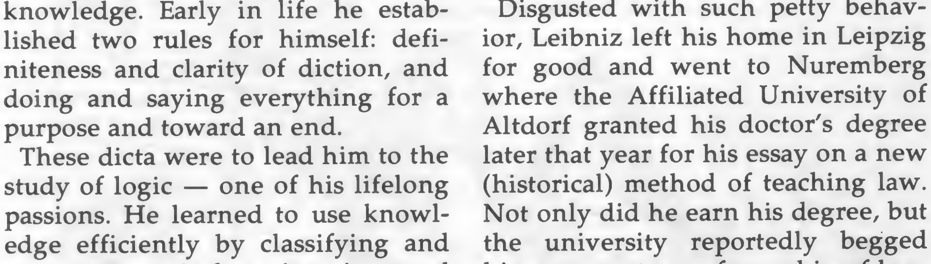


Photo Courtesy of IBM

**The Leibniz Calculator**

What Leibniz dreamed of, and his contemporaries ignored, was the concept now known as symbolic logic, which lay dormant until the 1840s. Besides the overall idea, Leibniz made several contributions to symbolic logic: namely, his formulation of the principal properties of logical addition and logical multiplication, negation, identity, the null class and class inclusion.

But it was not until almost two centuries later — when the English mathematician George Boole came to be — that anyone succeeded in adding logic itself to the domain of algebra. It is largely due to the work of Leibniz and Boole that the electronic computers of today evolved to carry out all the logical processes they foresaw so long ago.

Besides symbolic logic — which came to play such a major part in modern computing — Leibniz also saw the advantage of the binary number system for reducing his laws of thought to their simplest form and conducting the arithmetic manipulations he required. However, his vision of the binary system was ultimately confined to the spiritual.

"Leibniz saw in his binary arithmetic the image of creation," the French mathematician Pierre-Simon de Laplace wrote a century later. "He imagined that unity [one] represented God and zero the void; that the Supreme Being drew all beings from the void, just as unity and zero express all numbers in the system of numeration."

It would be another 300 years before the binary scale was found to be more applicable than the decimal scale to digital computers.

During his year at Nuremberg, Leibniz's curiosity led him to become a member of a secret society of the Rosicrucians, who were trying to find the "philosopher's stone."

It has been reported that Leibniz's method of gaining admission to the society was to collect from books on alchemy the most obscure phrases he could find, and to make of them an unintelligible letter, which he offered as evidence of his fitness for membership.

The society was so impressed that it appointed him to be its secretary. The chief gain to Leibniz in this association appears to have been his acquaintance with Baron von Boineburg, former minister to the Elector and Archbishop of Mainz, the most powerful man in the Empire.

The Baron presented a copy of Leibniz's essay on the historical method of teaching law to the Elector, who was as impressed with it as everyone else. After a personal interview, Leibniz was appointed to revise the code and before long he was being entrusted with various types of diplomatic missions.

Among the political plans he personally formulated was a holy war for the eventual capture and colonization of Egypt by the militarily ambitious King Louis XIV of France. The immensely powerful Louis XIV was then threatening the German Empire, still reeling from the Thirty Years War, and the plan was an attempt to divert his energies elsewhere.

In 1672, at the age of 26, Leibniz went by invitation to Paris to explain his project. While his advice was not taken, Leibniz was to spend the next four years — between missions — in Paris, studying mathematics under the tutelage of the physicist Christian Huygens. It was during this period that he became fascinated with mechanical contrivances.

In addition to studying the mechanical calculator of Pascal, Leibniz turned his attention to the devices of Sir Samuel Morland, the former secretary to Oliver Cromwell and then-current Master of Mechanics to King Charles II of England.

Among his other inventions, Morland replaced "Napier's Bones" with discs and became the developer, in about 1666, of an operable multiplier. His machine was composed of 12 plates, each of which showed a different part of the mechanism.

To operate his machine, a steel pin moved a series of dial plates and small indices, thereby allowing addition, subtraction, multiplication and division. Unfortunately, the device was clumsy and not always reliable and did not include automatic carry propagation.

Leibniz set about constructing a machine that would be more perfect and efficient than either Pascal's or Morland's. To begin with, he improved Pascal's device by adding a stepped cylinder to represent the digits one through nine. He is said to have considered gears with retracting teeth (later reinvented) and other mechanisms before settling on the cylinder with stepped teeth, now known as the Leibniz wheel.

In 1673, Leibniz built his perfected calculating machine, after making several different models. It was indeed superior to Pascal's and was the first general-purpose calculating device able to meet the major needs of mathematicians and bookkeepers.

Besides the machine that was widely used in his own time, Leibniz designed other ambitious calculating devices that proved too complex to be manufactured in the 17th century. The principles they pioneered, however, were exploited during the 19th and 20th centuries as precision engineering advanced.

A noteworthy example of such an achievement was a popular calculating machine developed in Alsace around 1820 by Charles Xavier Thomas de Colmar. It won a medal at the International Exhibition in London in 1862, and over the next 30 years approximately 1,500 were manufactured under the name "Arithmometer." Manufactured until the 1930s, the device was a somewhat refined and simplified version of Leibniz's design.

The Arithmometer's makers claimed it could multiply two eight-figure numbers in 18 seconds, could divide a 16-figure number by an eight - figure number in 24 seconds and could extract the square root of a 16-figure number in one minute. After the machine held a virtual monopoly for many years, the latter part of the nineteenth century saw considerable growth in the area of mechanical calculators, largely due to improved manufacturing methods.

One new design of that era was an alternative to Leibniz's stepped wheel, invented by Frank Stephen Baldwin in the U.S. in 1872. Machines based on Baldwin's design were made by W.T. Ohdner, and the device is now known as the Ohdner wheel. Besides having an improved carry mechanism, the Ohdner wheel was cheaper to make and more compact than the Arithmometer.

Although the Arithmometer had disappeared by about 1930, an ingenious small calculator called the Curta, based on the Leibniz wheel, was sold until it was displaced by modern electronic pocket calculators.

Shortly after developing his calculator, Leibniz was sent on a mission to London, where he spent some of his spare time attending meetings of the Royal Society. There he exhibited his machine, which so impressed the membership that they elected him a foreign member of the group before his return to Paris. In the same spirit he was elected to the French Academy of Sciences, becoming the first foreign member of that institution.

If one wonders how Leibniz found the time to accomplish all that he did in as many different areas as he did, it has been said that he had the ability to work anywhere, at any time and under any conditions. He read, wrote and thought incessantly.

He had no fixed hours for meals, but when a convenient opportunity came in the course of his studies, he sent out for something to eat. He slept little but well, according to reports. He often spent the night in his chair and sometimes would remain in it for several days at a time.

This allowed him to do a great deal of work, but it led to illness, for which he reportedly took remedies "more heroic than wise," since he disliked physicians, according to one historian.

In spite of his many idiosyncracies, he is said to have proposed marriage (when he was 50 years old). The object of his affections, however, took time to consider and, as the story

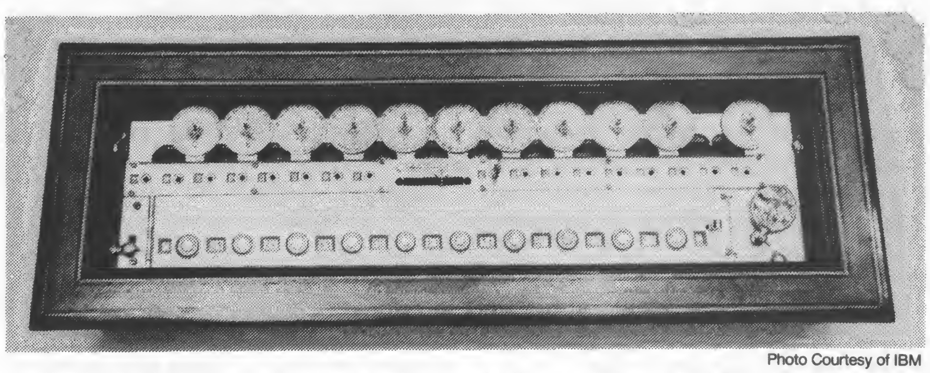


Photo Courtesy of IBM

**Morland's Multiplying Machine, Which Directly Inspired Leibniz's Work**

goes, that gave Leibniz time to consider as well, and he never married.

He enjoyed socializing with all sorts and conditions of men, believing that he could always learn something from even the most ignorant. He spoke well of everybody and made the best of everything, it is said, which no doubt explains the source of his theorem of optimism.

After developing the calculating machine, Leibniz returned to his mathematical studies and devoted all of his spare time to working out some of the elementary formulas that became "the fundamental theorem of the calculus." By 1675, he had presented the notation of differential and integral calculus.

This was not published until July 1677, however, 11 years after Sir Isaac Newton's unpublished discovery, which Newton made public after Leibniz's work had appeared.

Thus began a bitter controversy between them that was to last until Leibniz's death. While Newton may have developed his formulas before Leibniz, it is Leibniz's mathematical form, names and signs that have come to be used universally in preference to those of Newton.

Leibniz's remaining 40 years were spent in the service of the German house of Brunswick, as historian, librarian and chief advisor. In all, he served three masters in that capacity. His historical researches took him all through Germany and to Austria and Italy in the years 1687-90.

During his stay in Italy, Leibniz visited Rome and was urged by the Pope to accept the position of librarian at the Vatican. Since acceptance would have necessitated a conversion to Catholicism, Leibniz declined the offer.

Instead, he undertook the massive task of reuniting the Protestant and Catholic churches, which had split off early in the century. With little support for his efforts, Leibniz was forced to drop the ambitious project.

In his later years, Leibniz turned to philosophy as his main interest. He developed his theory of the universe, which he felt was composed of countless spiritual centers of force known as "monads." Each monad represents an individual microcosm, which mirrors the universe in varying degrees of perfection, and which develops independently of all other monads.

His last important contribution came in 1700 in Berlin, where Leibniz organized the Berlin Academy of Sciences and became its first president. After the Duke of Brunswick died in 1698, Leibniz gradually lost favor with his son and successor, George I, although he continued to work on the interminable family history.

When George I acceded to the throne of England in 1714, he failed to invite Leibniz to accompany him to England. Furthermore, his displeasure with Leibniz increased, possibly due to the influence of Newton's friends, whom he met there.

In his last years, Leibniz was almost entirely neglected and he died on November 14, 1716 at the age of 70, during an attack of gout. His death aroused no interest in London or Berlin and the only person present at his burial was his secretary. A year later in Paris, however, a fitting oration was presented by the French author Bernard Fontenelle.

Posterity treated Leibniz more kindly, however. Later in the century, the French encyclopedist Denis Diderot summed up Leibniz's capabilities nicely: "When one considers oneself and compares one's talents with those of a Leibniz, one is tempted to throw books away and seek some hidden corner of the world where one may die in peace. This man's mind was a foe of disorder: the most entangled things fell into order when they entered it."

And today, of course, Leibniz is regarded as one of the greatest minds of all time, having shown genius in just about every endeavor he attempted.

Courtesy of Charles Babbage Institute

# Part 3 . . . Charles Babbage: Man Before His Time

May you never again claim to feel frustration after reading the story of Charles Babbage, a man before his time who spent most of his life in the vain attempt to manufacture a machine considered by most of his contemporaries to be utterly ridiculous.

In thousands of detailed drawings made 150 years ago, Babbage projected the fundamentals on which today's computers operate, but his ideas were met almost universally with a veil of ignorance and misunderstanding. If the technology of the 19th century had been equal to Babbage's genius, a computer would have been built in 1822.

But the technology was not there and Babbage was destined to see the fruits of his labor only on paper and in theory. More than a century later, however, Howard Aiken, director of Harvard University's Mark I computer project, remarked, "If Babbage had lived 75 years later, I would have been out of a job." The historic Mark I, completed in 1944, was conceptually very similiar to Babbage's machine.

Charles Babbage was born on Dec. 26, 1791, in Totnes, Devonshire, England, into the fascinating and tumultuous epoch of the French Revolution. He was one of two surviving children of Benjamin Babbage, a banker, and Betty Plumleigh Teape, both of Totnes and both descended from well-known Devonshire families.

As a child, Charles Babbage displayed a great inquisitiveness into the causes of mechanical workings. Upon receiving a new toy, he reportedly would ask, "Mamma, what is inside of it?" If the forthcoming answer was not to his satisfaction, the child would proceed to take the object apart to satisfy his curiosity.

Besides things mechanical, Charles nurtured an early interest in the occult. While still a child, he once attempted to prove the existence of the devil by drawing a circle in his own blood on an attic floor while reciting the Lord's Prayer backward.

With no conclusive results from that experiment, his interest in the supernatural continued. Charles arranged with a boyhood friend that whoever died first would appear to the survivor. When his friend died at the age of 18, Charles stayed awake all night awaiting an apparition that never came. Even in his college years, Charles formed a ghost club to collect reliable evidence supporting the existence of the supernatural.

After a classical education at an old and venerable boys grammar school, Charles entered Trinity College in Cambridge, England. There he continued his record of boyish pranks and rebellion that resulted largely from the boredom of one who often knew more than his instructors.

Despite his unorthodox behavior, Charles was well on his way to absorbing the advanced theories of mathematics. With several others, he formed an Analytical Society to present and discuss original papers on mathematics and to interest people in translating the works of several foreign mathematicians into English.

### Seed Is Planted

At Cambridge, Charles' studies led him to a critical examination of the logarithmic tables used to make accurate calculations. He was well aware of the difficulty and tediousness of compiling the astronomical and nautical tables that were indispensable to the great maritime nation and he was constantly finding and reporting errors in existing tables.

During a free moment, Charles was contemplating a problem while sitting in a room of the Analytical Society. Upon seeing Charles apparently in some far-off world, a friend asked him the nature of his dream. It is told that Charles pointed to some logarithmic tables and said, "I am thinking that all these tables might be calculated by machinery."

The idea took firm hold in Charles' mind and after graduation he returned home to begin sketching a machine by which all mathematical tables could be computed by one uniform process. He became convinced it was technically feasible to construct a machine to compute by successive differences and even to print tables when they were computed, thereby avoiding the numerous compositors' errors. It is noteworthy that Babbage's ambitious venture was undertaken 50 years before typesetting machines or typewriters were invented.

While still formulating the plans

for his machine, Babbage at 23 married 22-year-old Georgiana Whitmore, exactly one year before the 1815 Battle of Waterloo. Georgiana was to have eight children in 13 years, only three sons of whom survived to maturity. Four sons died in infancy or childhood and their only daughter died in her late teens.

It is said Babbage took almost no interest in the upbringing of his children and instead retired to his library for hours at a time, concentrating on technical problems in a manner approaching obsession. When Georgiana died at age 35, Babbage's mother assumed complete care of the children, from whom Babbage chose to live completely apart. He was not to remarry in his 80-year lifetime.

Two years after his marriage, in 1816, Babbage had his first taste of worldly failure, followed closely by another. His application for the professorship of mathematics at East India College in Haileybury was rejected due to political reasons, as was his application, three years later, for the chair of mathematics at the University of Edinburgh, glittering recommendations notwithstanding.

Fortunately, the elder Babbage gracefully supported Charles and family, while Charles continued his feverish work on calculating machines. By the time he was 30, Babbage was ready to announce to the Royal Astronomical Society that he had embarked on the construction of a table-calculating machine.

His paper, "Observations on the Application of Machinery to the Computation of Mathematical Tables" was received with wide acclaim and Babbage was presented the first gold medal awarded by the Astronomical Society.

### Appeals to Royal Society

Now determined to similarly impress the prestigious Royal Society, Babbage wrote a letter to its president, Sir Humphrey Davy, stating that the "intolerable labour and fatiguing monotony" of a continued repetition of similar mathematical calculations had first excited his desire and afterwards suggested the idea of a machine that "by the aid of gravity or any other moving power" should become a substitute for one of the "lowest occupations of the human intellect."

A 12-man committee considered Babbage's appeal for funds to complete his project and in May 1823 the Society agreed that the cause was worthy. In July, Babbage received £1,500 "to enable him to bring his invention to perfection in the manner recommended."

In developing his Difference Engine, as Babbage called it, Babbage studied the mathematical inventions of several predecessors, notably the work of Charles Mahon, Third Earl of Stanhope (see related story). While he drew heavily on Stanhope's principles, what distinguished Babbage's design from all previous work was this:

That it proposed to calculate a series of numbers following any law by the aid of differences and that by setting a few figures at the outset, a long series of numbers was readily produced by a mechanical operation.

Besides the gradually apparent implementation problems connected with the Difference Engine, problems also arose from a misunderstanding between Babbage and the British Government, both of whom regarded the machine as the property of the other. This misunderstanding, which caused problems for the next 20 years, at first delayed Babbage's work on the engine while he awaited further funds beyond the initial grant.

Finally begun, the engine endured many permutations, improvements and modifications over the next four years, each one setting progress back to square one because of the need for specially created tools to construct the unheard-of parts of the machine.

Babbage apparently had miscalculated his task. Constructing the Engine would have cost about 50 times the money he was given. Furthermore, he needed two tons of novel brass, steel and pewter clockwork, that had to be made since it was then unavailable.

In 1827, in the midst of Babbage's professional difficulties, he was overwhelmed by a series of personal tragedies: the deaths of his father, wife and two of his children. At the same time, rumors were beginning to circulate regarding the expense of the engine and questioning its value. Babbage estimated he had already spent about £6,000 on the engine.

Events took their toll and Babbage fell ill. His family advised him to travel abroad for several months to regain his equilibrium. On his return, Babbage approached the Duke of Wellington, then prime minister, regarding the possibility of a further grant.

In the victor of Waterloo, Babbage found someone who could truly grasp the principles and capabilities of his machines, and the two remained friends for the rest of the duke's life. The British government shortly after granted another £1,500 followed by £3,000 more, with a promise to furnish remunerative sums upon completion of the machine.

Babbage also had inherited £100,000 upon the death of his father — a sum from which he was often

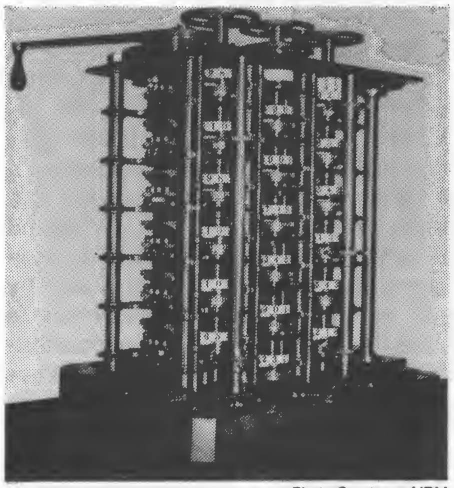
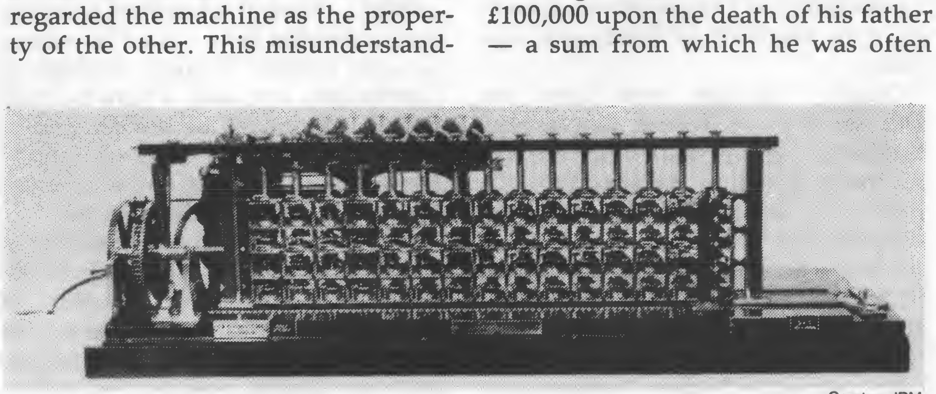


Photo Courtesy of IBM

**Babbage's Difference Engine as Reconstructed From His Writings**



Courtesy IBM

**George Scheutz's Calculator, Inspired by, But Different From, Babbage's**

obliged to "borrow."

After fitful work on the Difference Engine, Babbage was faced with more problems, this time surrounding the chief engineer on the project, Joseph Clement, who demanded more and more exorbitant sums for work completed. The matter culminated in the engineer's quitting work on the engine and firing all his workmen.

In the midst of his considerable troubles, Babbage turned his attention to other things, running unsuccessfully for Parliament and publishing numerous technical works, including his *Economy of Manufactures* (1832), now considered a pioneer work on operational research. The main theme was the division of labor, applied to mental as well as to mechanical operations.

### The Analytical Engine

While deprived of his tools and drawings by Clement, Babbage was struck by yet another brainstorm — he would design a machine that would be easier to construct, have greater versatility and operate faster than the Difference Engine.

His new inspiration, the Analytical Engine, would go beyond the Difference Engine and perform all arithmetic calculations — as opposed to a limited set — and would combine such operations to solve any conceivable arithmetic problem.

The Analytical Engine included most of the essential features of today's digital computers, expressed in mechanical terms. The machine was to be divided into two parts: the "mill," in which arithmetic processes were carried out, and the "store," which contained the data to be worked on, as well as intermediate results.

The store would consist of 1,000 registers, each containing a 50-digit number. Numbers could be selected from the store, operated upon and the result returned to another location in the store.

The control of the whole process was to be carried out through a set of punched cards similar to those used in the Jacquard weaving loom, invented in 1801 and still in use today. Jacquard looms allowed the weaving of elaborate patterns as easily as older looms made plain cloth, since the pattern of holes on each card — indicating the weaving design — was read by plungers that passed through them.

Babbage proposed to use the cards both to specify the operation to be carried out and to give the address of the operand in the store. He also envisioned using another set of cards, the number cards, to feed data into the machine, although it appears he expected the store registers to be set up by hand with the constants required.

An all-important feature of the Analytical Engine was its ability to make conditional jumps. Mechanical means were provided to allow a band of cards to be advanced or backed, thereby jumping some cards, or repeating them.

### Enter Lady Lovelace

"We may say most aptly that the Analytical Engine weaves algebraical patterns just as the Jacquard-loom weaves flowers and leaves. Here, it seems to us, resides much more of originality than the Difference Engine can be fairly entitled to claim."

Those words were written by Lady Ada Augusta Lovelace, the only legitimate offspring of the poet Lord Byron and a woman who was to dedicate the last decade of her short life to interpreting Babbage's Analytical Engine.

Now considered the first "programmer," Lovelace, like Babbage, was way ahead of her time, insisting on pursuing major intellectual ideas in an age when women were expected to voice their thoughts through their husbands, if at all.

Dark, delicate and considered beautiful, Lovelace was 27 when she translated from French to English L.P. Menabrea's paper dealing with the Analytical Engine. A mathematical genius in her own right, Lovelace took Babbage's suggestion and added

Courtesy of Culver Pictures

**Ada Lovelace**

some notes to the paper, resulting ultimately in a work three times the length of the original manuscript.

By 1843, at age 28, Lovelace had mastered Babbage's plans for his engine and was as obsessed with the concept as he. Having the good fortune to be married to a man who encouraged her intellectual progress, as well as who could afford help to care for their three children, Lovelace channeled most of her talent and energy to further Babbage's cause, eventually correcting some serious errors in his work.

One of her seminal ideas was that a large calculation might contain many repetitions of the same sequence of instructions, and she pointed out that by using the conditional jump facility, it should be possible to prepare only a single set of cards for the recurring instructions. She thus described what we now call a "loop" and a "subroutine."

Her ideas were extended a century later by the British mathematician Alan M. Turing in 1937 and by John von Neumann in 1946 — both of whom were instrumental in the development of the modern electronic digital computer.

The woman who possessed such vision and insight was to meet an excruciating end from cancer, at the age of 36, leaving Babbage once again alone to continue his unrewarding labors.

In all, Babbage was to spend 14 years and £17,000 on the Difference and Analytical Engines, neither of which would be built in his lifetime. Time and again, prestigious posts that had been promised him would escape his grasp, the British government would completely withdraw its financial support and, ultimately, the general feeling toward him and his machines was adverse.

Ironically, Babbage's dream was to be partially realized by a Swedish printer, George Scheutz, who built a similar, workable calculator after reading an article on the Difference Engine on the *Edinburgh Review* in 1834.

Scheutz and his son began work on the machine, designed for computing mortality tables, in 1837. Quite different in principle from Babbage's machine, Scheutz's Tabulating Machine was much smaller and consisted of four differences and 14 places of figures, but it could print tables.

To everyone's surprise, Charles Babbage did everything in his power to ensure the success of the new machine and was undoubtedly instrumental in its being awarded the French Gold Medal in 1855.

The first model was purchased for $5,000 in 1856 and sent to the Dudley Observatory in Albany, N.Y. and a duplicate was made for the British government and used in the registrar general's department.

Babbage's gracefulness and cooperation are not so puzzling when one considers the following: his own machine had inspired Scheutz; Scheutz's was infinitely less ambitious than his own and therefore much easier to complete; and its very existence proved that a calculating machine of this type not only could be made, but could work.

Now in old age, Babbage at 71 agreed to have the completed section of his Difference Engine shown to the public for the first time. Presented at the Great Industrial Exhibition in London in 1862, the engine was finally shown, albeit "in a small hole, four feet, four inches in front by five feet deep," as Babbage put it. It was surrounded by other exhibits and no more than six or seven people could examine it at any one time.

Babbage's many disappointments led him to say he had never had a happy day in his life and one of his friends observed that he spoke as a man who "hated mankind in general, Englishmen in particular and the English government . . . most of all."

On Oct. 18, 1871, two months short of his 80th birthday, Charles Babbage was close to death. "It's a long time coming," he said to a friend. "Now I am going, as they call it, to the other world: Ask me any question you like as to my feelings or thoughts and I will tell you."

History does not record what questions or answers may have been given, but it does note that only a handful of mourners were at his burial six days later — proof that a man's greatness cannot be judged by the opinions of his contemporaries.

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# *Earl of Stanhope Laid Foundation for Babbage's Engine*

The foundation for Charles Babbage's calculating engine was an arithmetic machine developed in 1777 by an eccentric, well-born politico named Charles Mahon, Third Earl of Stanhope.

Mahon's grandfather was a commander in the War of the Spanish Succession and Prime Minister for King George I (the same George I who failed to invite Gottfried Leibniz to England when he acceded to the throne) and his grandmother was the daughter of Governor Pitt. Mahon's father devoted most of his life to science and became a prominent intellectual rather than a member of politics and society.

Born in London on Aug. 3, 1753, Charles Mahon was the only surviving child of his parents. At the age of nine, he was sent to Eton School, where he displayed strong indications of his mechanical and mathematical interests.

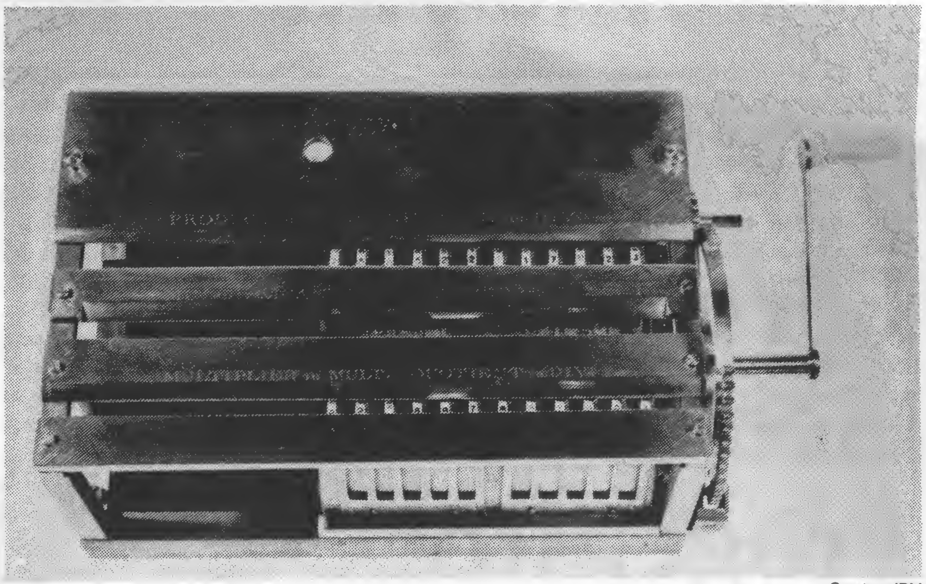
In his 19th year, he was sent to Geneva, Switzerland and placed under the tutelage of the celebrated French jurist and writer Alain Rene Le Sage. Applying himself to geometry, mechanics and philosophy, Mahon soon won a prize offered by the Swedish Academy for the best essay written on the construction of the pendulum. At 19, he was elected a fellow of the Royal Society.

Married at 24 to his second cousin, Lady Hester Pitt, Mahon that same year invented two calculating arithmetic machines. The first, "by means of dial-plates and small indices, moveable with a steel pin, performed with undeviating accuracy" complicated sums of addition and subtraction.

The second solved problems in multiplication and division "without the possibility of mistake" by the revolution of a small winch. It was half the size of a common table writing-desk and "what appears very singular and surprising to every spectator to this machine is that in working division, if the operator be inattentive to his business and thereby attempts to turn the handle a single revolution more than he ought, he is instantly admonished of his error by the springing up of a small ivory ball."

Of great importance was Mahon's use of gear wheels and a 10s-carrying device. The machine contained a series of toothed wheels, having wide faces bearing 10 long teeth.

The first tooth, which reached completely across the face, represented nine and the next tooth was one-ninth shorter, the next one-eighth shorter and so on down the line. To add nine, the toothed wheel was moved along so that the nine teeth would engage; to add eight, it was moved so eight would engage.



Courtesy IBM

**One of Charles Mahon's Early Calculating Machines**

### Champion of Common Man

A man of great versatility, three years after Mahon invented his arithmetic machines, he became a member of the Lower House (in 1780) and in 1786, a peer in the House of Lords.

He was chairman of the Revolution Society, which sympathized with the French Revolution, and in 1795 he introduced into the House of Lords a motion denouncing any interference with France's internal affairs — a point on which he was, characteristically, a minority of one.

As a Whig (conservative), Mahon fought for parliamentary reform, abolition of slavery, freedom of the press and for the independence of jury courts.

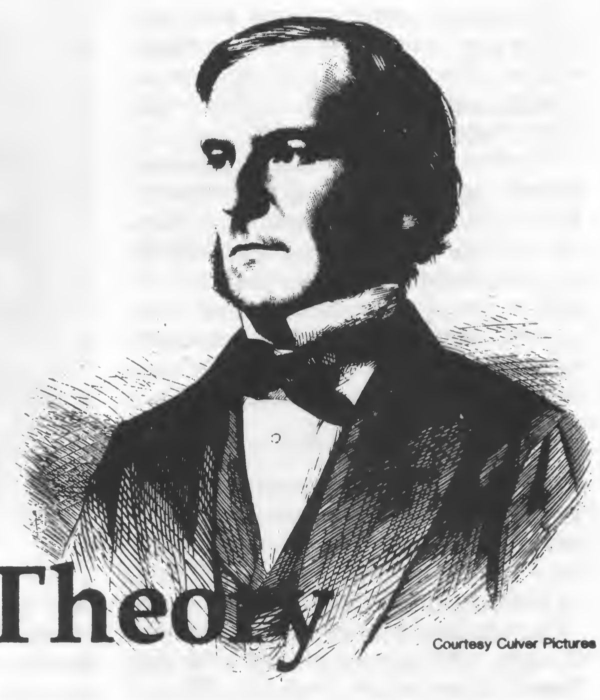
Besides his arithmetic machines, Mahon developed what is considered to be the world's first logic machine, the "Stanhope Demonstrator." No only could the device be used for solving traditional syllogisms by a method closely linked to the Venn circles, but it also handled numerical syllogisms as well as elementary problems of probability.

Inventive in areas other than mathematics, Mahon is credited with devising a scheme for fireproofing buildings, a method of roofing houses, a kiln for burning lime, a steamboat and a double inclined plane for improving the operation of canal locks.

He also evolved a plan for preventing forgeries in coin and bank notes, developed a monochord for tuning musical instruments, a microscopic lens and, in the realm of printing, he invented the sterotype printing press that bears his name.

Reportedly odd in his dress and person, Mahon was said to be completely unaffected in his manners — a remarkable trait in one of such high rank. The Earl of Stanhope died on Dec. 15, 1816, deeply lamented by all, especially the humbler class of citizens for whom he had worked so hard.

# Part 4 . . .
# George Boole: Progenitor Of Information Theory



Courtesy Culver Pictures

*"Pure Mathematics was discovered by Boole in a work which he called* The Laws of Thought."

— Bertrand Russell

All the geartrains, stepped wheels, vacuum tubes or printed circuit boards in the world do not a computer make. Besides the immensely important mechanical developments of Pascal, Leibniz and Babbage, it took an entirely original theory of logic to ultimately breathe life into the machines that "think."

Expanding on Leibniz's "general method in which all truths of the reason would be reduced to a kind of calculation" — set forth 188 years earlier — English mathematician George Boole in 1854 laid the groundwork for what we know today as Information Theory through the publication of his masterpiece, *An Investigation of the Laws of Thought, on which are founded the Mathematical Theories of Logic and Probabilities.*

In this work, published when the author was 39, Boole reduced logic to an extremely simple type of algebra, in which "reasoning" is carried out through manipulating formulas simpler than those used in second-year traditional algebra.

His theory of logic, which recognizes three basic operations — AND, OR and NOT — was to become germane to the development of telephone circuit switching and the design of electronic computers. As with Leibniz's ideas, however, Boolean algebra was neglected for many years after it was proposed.

Nevertheless, few mathematical works of the past century have had as great an ultimate impact on mathematics and philosophy than Boole's book. The significance of the work, recognized by Boole's contemporary, the logician Augustus De Morgan, was expressed by that mathematician:

"That the symbolic processes of algebra, invented as tools of numerical calculation, should be competent to express every act of thought, and to furnish the grammar and dictionary of an all-containing system of logic, would not have been believed until it was proved in *Laws of Thought.*"

George Boole was born Nov. 2, 1815, in Lincoln, England, the son of a poor shoemaker. Although a contemporary of Charles Babbage, Boole was not born into the same privileged class as Babbage, but rather was a member of the "lower classes," a circumstance that made his early life extremely difficult.

Sprung from a stratum of society in which children were not expected to, and in fact were discouraged from, attending the university, George had to educate himself entirely on his own.

Even though the Industrial Revolution was well under way in England, a knowledge of the ancient languages was still considered to be the mark of a gentleman. Naturally, no Latin or Greek were taught at the school Boole was allowed to attend.

Believing such knowledge was necessary if he ever wanted to rise above his humble beginnings, Boole taught himself Greek and Latin, with his father's unschooled encouragement, and at the age of 12 managed to translate an ode of Horace into English verse.

Understanding nothing of the technical merits of the translation, but understandably proud, Boole's father had it printed in the local paper. A scholarly debate ensued, which proved both flattering and humiliating to Boole.

While one classical master contended that a boy of 12 could not have produced such a translation, on the other hand, some grave technical defects were criticized. Determined to perfect his knowledge of Latin as well as Greek, Boole spent the next two years slavishly studying the two languages, again without help.

Although these studies were not enough to transform him into a true gentleman, such drudgery reinforced his already strong self-discipline and contributed to the classical style of Boole's mature prose.

Considering the fact that his father quit school after the third grade, it is amazing to learn that Boole got his early mathematical training from his father, who had somehow managed to educate himself in at least that area.

By the age of 16, it became necessary for Boole to go to work to help out his parents. Taking a job as an "usher," or assistant teacher, in an elementary school, Boole was to spend four years teaching in two different schools.

Always with an eye toward improving his station in life, Boole began to consider the few options open to him. Since teaching, at the level he was practicing it, was not considered a profession or even a reputable trade, Boole looked to the church for his social salvation. He would become a clergyman.

When he was not teaching, Boole spent his time in serious study of French, German and Italian in preparation for his ecclesiastical life. Unfortunately, his family's poverty once more disrupted Boole's plans; his parents urged him to forego the religious life in view of their ever-deteriorating financial situation.

Responsive as always to his parents' needs, Boole decided to open a school of his own. His age: 20. While acting as a teacher, Boole always considered himself a student as well and proceeded to teach himself the entire body of higher mathematics as it then existed.

It is probable that he tackled the *Mecanique Celeste* of Pierre-Simon de Laplace, described by the historian E.T. Bell as "one of the toughest masterpieces ever written for a conscientious student to assimilate, for the mathematical reasoning in it is full of gaps and enigmatical declarations that 'it is easy to see.'"

He also would have been likely to study the "excessively abstract *Mecanique Analytique* of [Comte Joseph Louis] Lagrange, in which there is not a single diagram to illuminate the analysis from beginning to end," according to Bell.

Yet Boole, whose mind apparently was designed to easily understand and absorb just such abstractions, was successful enough to produce his first written contribution to mathematics based on these extremely difficult studies — a paper on the calculus of variations.

Early in his mathematical career, Boole made a discovery that could have been made by any of his established and more experienced contemporaries and without which it is said the theory of relativity would have been impossible. He discovered invariants.

The fact that Boole saw what others overlooked and, even more important, recognized its significance, foreshadowed his future mathematical breakthroughs, which would not be truly appreciated until proven practical nearly a century later.

Once Boole's mathematical career got off the ground with the publication of his first paper, the question was: How to make his ideas known at a time when opportunities for mathematical publication were limited? Boole did not belong to any of the learned societies that maintained their own journals, although he gradually developed friendships with many of the leading British mathematicians, either personally or through correspondence.

One such friendship was with the Scottish mathematician D.F. Gregory, who founded *The Cambridge Mathematical Journal* in 1837. Boole submitted some of his work, the originality and style of which greatly impressed Gregory. Not only had Boole found a vehicle for publishing his work, he had found a lifelong friend.

Part of the credit for Boole's later development of his theory of logic must be given to the intellectual climate in England at the time — exemplified by the British mathematical "reformers," including Babbage, Gregory, George Peacock, John Herschel and De Morgan, who together created the basis for the modern conception of algebra.

It was Peacock who, in his 1830 work, *Treatise on Algebra*, broke away from the idea that the "x,y,z" in such relations as "x+y=y+x," "xy=yx" and "x(y+z)=xy+xz" necessarily represent numbers. They do not. Rather, they are arbitrary marks, combined according to certain operations and symbolized by "signs" in accordance with established postulates.

This renovation of algebra afforded Boole the chance to do work that was appreciated by his contemporaries, although — without practical application in his own century — symbolic logic was to lie fallow for many decades. As late as 1910, for example, eminent mathematicians scorned it as a "philosophical" curiosity without mathematical significance.

It was the occasion of an ongoing intellectual "debate" between the Scottish philosopher Sir William Hamilton and De Morgan on the merits of mathematics — or lack thereof, according to Hamilton — that caused Boole to publish the seminal *Mathematical Analysis of Logic* in 1848. The slim volume, meant as a defense of De Morgan, was the prelude to Boole's masterpiece, published six years later.

With the publication of the *Analysis*, the vision and brilliant insight of this quiet, simple man became apparent to his mathematical friends, who encouraged him to enter Cambridge for some orthodox mathematical training.

Boole reluctantly turned down those suggestions because his parents had become entirely dependent upon him for support. Continuing his teaching chores without complaint, Boole finally got a break in the following year, 1849, when he was appointed Professor of Mathematics at the newly opened Queen's College in what was then called Cork, Ireland.

The appointment allowed him to devote more time to his *Laws of Thought*, which he continually honed and perfected for five more years, until its publication in 1854.

As Boole wrote in the first paragraph of the book: "The design of the following treatise is to investigate the fundamental laws of those operations of the mind by which reasoning is performed; to give expression to them in the symbolical language of a Calculus, and upon this foundation to establish the science of Logic and construct its method; to make that method itself the basis of a general method for the application of the mathematical doctrine of Probabilities; and, finally, to collect from the various elements of truth brought to view in the course of these inquiries some probable intimations concerning the nature and constitution of the human mind."

And later in the chapter: "Now the actual investigations of the following pages exhibit Logic, in its practical aspect, as a system of processes carried on by the aid of symbols having a definite interpretation, and subject to laws founded upon that interpretation alone. But at the same time they exhibit those laws as identical in form with the laws of the general symbols of algebra, with this single addition, viz., that the symbols of Logic are further subject to a special law . . . to which the symbols of quantity, as such, are not subject."

In other words, while it is not true in common algebra, for example, that every "x" is equal to its square, it *is* true in the Boolean algebra of logic. According to Boole, $x^2=x$ for every "x" in his system. In numerical terms, of course, this equation has "0" and "1" as its only solutions. Therein lies the importance of the binary system for modern computers — their logical parts are in effect carrying out binary operations.

Besides logic, Boolean algebra has at least two other important applications. The first of these stems from the fact that it is the natural algebra with which to treat the combination of sets of elements under the operations of intersection and union of sets. Considering also the idea of "number of elements" in a set, Boolean algebra becomes the foundation for the theory of probability.

In spite of its subsequent importance — to many other branches of mathematics as well as the development of the computer — Boole's monumental work was to remain only a curiosity for many years. Like Babbage, Boole was a man ahead of his time. It was not until Alfred North Whitehead and Bertrand Russell published their 3-volume *Principia Mathematica* (1910-1913) that serious mathematicians began to study formal logic.

It is noteworthy that, while Boole's accomplishments depended partly on the mathematical originality already in evidence in England, including the ideas of Babbage, Babbage is said to have drawn from Boole's work as well. Mathematicians point out that Babbage's understanding of the notion of a mathematical operation and the quantities upon which it operated was made possible by the group of British algebraists to which Boole belonged.

Because Boole demonstrated that logic can be reduced to very simple algebraic systems, it was possible for Babbage and his successors to design mechanical devices that could perform the necessary logical tasks.

The year after he published his *Laws of Thought*, Boole married Mary Everest, niece of the Professor of Greek at Queen's College. The marriage would last only the nine years remaining before Boole's untimely death at the age of 49.

Honored and with a growing fame, Boole died on Dec. 8, 1864, of pneumonia reportedly contracted after he kept a lecture engagement even though he was soaked to the skin.

Mary Boole, who had become a devoted disciple of her husband, published a pamphlet after his death in which she stated some of his ideas — no doubt stemming from his many years as a teacher — on the need to rationalize and humanize the education of young children.

In *Boole's Psychology*, Mary Boole recounted a significant event in the life of George Boole: He told his wife that when he was about 17, it "flashed upon" him as he walked across a field that besides the knowledge gained from direct observation, man derives knowledge from some undefinable and invisible source, which Mary Boole called "the unconscious."

Further evidence of his belief lies in the closing pages of *The Laws of Thought*, in which Boole cites "the error of those who regard the study of Mathematics, and of their applications, as a sufficient basis either of knowledge or of discipline."

Boole was, if anything, logical and disciplined. Nevertheless, he demonstrated his all-important broad vision of the world in his statements, which he felt "to some . . . will appear foreign to the professed design of this work."

Nevertheless, Boole wrote: "If the mind, in its capacity of formal reasoning, obeys, whether consciously or unconsciously, mathematical laws, it claims through its other capacities of sentiment and action, through its perceptions of beauty and of moral fitness, through its deep springs of emotion and affection, to hold relation to a different order of things . . . As truly . . . as the cultivation of the mathematical or deductive faculty is a part of intellectual discipline, so truly is it only a part."

It was the powerful combination of intellect and intuition in George Boole that resulted in the several mathematical milestones he contributed, the effects of which will undoubtedly be felt for many ages to come.

# *C.E. Shannon Put It All Together*

It was in 1937 that MIT graduate student Claude Elwood Shannon put two and two together and showed that Boolean algebra could be applied to problems of switching circuits.

As his master's thesis in electrical engineering, Shannon published a paper entitled, "A Symbolic Analysis of Relay and Switching Circuits," applying Boole's symbolic logic to the analysis of switching circuitry and showing how logical algebra could be performed by relays.

Some credit the thesis with having laid the foundation for the use of the binary number system in place of the decimal system in the computer. Shannon himself is a bit too modest to make such a claim. Nevertheless, it is generally agreed that his profoundly original analysis proved to be a milestone in the development of digital computers and helped bring the world full-speed into the Information Age.

Since switching circuits are at the heart of automatic telephone central exchanges, Shannon's ideas first proved perfectly useful for the Bell Telephone Laboratories. Shannon went to work for Bell as a mathematician in 1941 and moved "from triumph to triumph" there, in the words of his former MIT professor Norbert Wiener, developer of the concept of "cybernetics."

One of Shannon's triumphs at Bell was the publication in 1948 of his "Mathematical Theory of Communications," in which he showed systems engineers how to eliminate noise by encoding signals. That theory spawned a major effort toward achieving reliable communications with low error rates.

Shannon's interests eventually extended to the development of the mechanical mouse, the automatic chess player, mathematical cryptography and the entire scope of modern information theory.

In a 1973 magazine interview, Shannon was asked what he felt information theory's future was at the time of his original publication. "I was quite surprised at the publicity and reaction," he recalled. Last month, now looking back more than 40 years, Shannon recalled that the immediate acceptance and publicization of his ideas "was the highlight of my life at that time."

How did he reach his brilliant conclusions? "I had studied Boolean algebra as a course in philosophy," Shannon recalled. Then, as an MIT graduate student, Shannon worked on Vannevar Bush's analog computer, the historic "differential analyzer."

"And part of that machine was a very complex relay circuit," he explained. "I had to kind of, you know, fix that from time to time to keep it going and in so doing I got interested in the logic of relay circuits. And relay circuits are really the same thing as computing circuits.

"In working with these and thinking about that, it became obvious that the natural mathematics to use for relays or switching circuits was that of Boole."

Shannon's "obvious" solution got him the 1939 Noble Prize from the American Institute of Electrical Engineers, when he was 23.

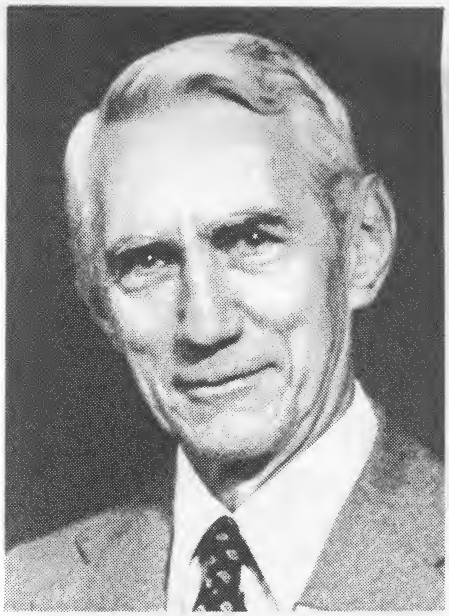
Now 65, Shannon is retired and relatively inactive in the field, although he remains a member of the Board of Directors of Teledyne Corp. He lives with his mathematician wife, Betty Moore Shannon, and their three children in Winchester, Mass. Shannon now devotes most of his time to jogging, juggling, occasional unicycle-riding (several models of which he has designed and built), listening to jazz and investing in stocks.

And what of the future of Information Theory? Many have tried to apply its concepts to areas far outside the domain of electronic communications — psychology, art, theology and semantics — but without much success. The real future of the discipline lies in artificial intelligence, Shannon feels.

"Computers, as people think of them today, are one thing," Shannon said, "but I visualize the possibility of complicated robot-type devices to carry out very sophisticated intellectual jobs."

While computers already can do such "shop work" as household bookkeeping, banking and census functions, Shannon predicts an evolution to such responsibilities as letter writing and "servant"-like functions in the decades ahead.

A perfect example of the sophisticated intellectual contributions possible is the recently solved "four-color theorem," a problem that puzzled mathematicians for a century, according to Shannon. Computers have not only figured out how to color a map with four colors so no contiguous countries have the same hue, but also have proven that only four colors are ever required for a two-dimensional map.



**C.E. Shannon**

Naturally, "the computer had a lot of help from the programmers," but the computer "did the dirty work, the hard work of trying out many different cases," Shannon observed.

"So in a way, the computer will work hand-in-hand with people and will do the things that require a lot of time and detail. The symbiosis of these two will be, I think, a terrific thing."

Courtesy Burroughs Corp.

# Part 5 . . . William Burroughs: Liberation From Calculation

*"Accuracy is truth filed to a sharp point."* — William S. Burroughs

It was the monotonous drudgery of his job that inspired a young bank clerk in 1882 to attempt to build an adding machine that would be accurate, fast and easy to operate.

Nearly two decades of frustration and repeated failures would pass before William Seward Burroughs succeeded in his struggle, but his success would be just the beginning in the life of a company that has evolved into a giant of the computer industry.

The first American to be considered in this history of computing was born to a rather unsuccessful mechanic on Jan. 28, 1857 in Rochester, N.Y., although the family soon moved to Lowell, Mich.

Moving to Auburn, N.Y., several years later, William attended public school there, although he never went to college. Upon the completion of William's education, his father got him a job in a local bank as an accountant and bookkeeper. The elder Burroughs was determined that his son not become a mechanic.

William proved to be a tireless worker, even though the nature of the work was tedious and often required him to add, check and recheck long columns of figures far into the night. He is said to have reflected that half his time was spent guarding against errors and a quarter of his time hunting for errors that had been made.

For a young man of 25, it was not a very exciting life. The world, however, was going through a period of excitement, one that would soon be demanding that the millions of columns of numbers in offices everywhere be added faster than ever before.

The transcontinental railroads were moving merchandise and mail more and more swiftly, creating a need for centralized and timely records. The telephone was on its way into the nation's offices, promising to reduce the time available for preparing statements of account or for searching out errors hidden in day books.

The future would belong to the swift and Burroughs wholeheartedly entered the race against time. After five long years at the bank, he lifted his vision above the endless columns of numbers and determined to make a truly valuable contribution to humanity — an adding machine that would liberate workers from the tedium of calculation.

It was 1882. Burroughs' health had deteriorated from long hours of work and his doctor advised a warmer climate and a more physically active occupation. St. Louis became his new home and mechanic his new title (his father's earlier wishes notwithstanding).

Because Burroughs knew little of mathematics, design or the properties of materials, he rightly felt that the machine shop could teach him some valuable lessons he could apply toward his goal.

At Boyer Machine Co., it soon became clear Burroughs was a natural. He quickly acquired a reputation for special skill and when an intricate mechanism needed repairs, he usually made them.

Joseph Boyer, the owner of the shop, had occasionally observed Burroughs at work. Among other things, Burroughs made a collapsible chicken coop — a device that could be folded up and stored when not in use. So it is little surprise that Boyer once reportedly told someone seeking a helper, "I can't say where you can get a man, stranger, but I've got a boy you can use right well. This boy will do you more good than any man I have in the place."

Besides his regular work, Burroughs commonly spent his evenings and nights designing on paper the machine he hoped to build. His dream was to construct a machine that would record amounts on paper, add these figures and carry a progressive total, so that at any time one could press a key for a total up to that point.

Borrowing some concepts from the recording-adding machine then being developed by Dorr Eugene Felt (see related story), Burroughs hoped to improve upon that excellent and practical machine.

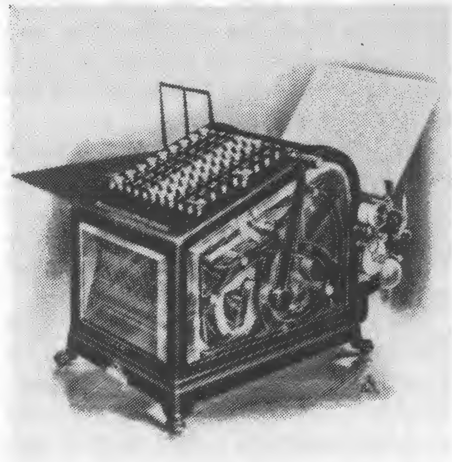
The only thing he lacked was money. Fate, however, brought Burroughs into contact with someone who was interested — and influencial — enough to help round up some capital. That person was a dry goods merchant, Thomas Metcalf, for whom Burroughs had repaired some machines. Within a few weeks, Burroughs and friend had raised $700, which allowed him the luxury of the materials he needed.

Although he drew his first machine plans on paper, the fluctuations of weather caused the sheets to expand and lose their precision. So Burroughs began to make drawings with the point of a needle on polished sheets of copper.

Eyestrain resulted, so that he then began drawing plans on polished zinc that had been chemically blackened. The white lines on a black background proved it to be a workable and accurate method, which he continued to use.

Success was not to come easily to Burroughs. His money used up, he was faced with the failure of his first machine model, completed in 1884. Dismayed but not discouraged, Burroughs doggedly worked on — sometimes for 48 hours without stopping — and soon produced a second model.

Although the second model also failed, Burroughs in 1885 applied for patents and in the following year, in



Courtesy Burroughs Corp.

**Burroughs Adding and Listing Machine**


Courtesy Burroughs Corp.

**Birthplace of the Adding and Listing Machine**

the state of Missouri, the American Arithmometer Co. was formed. The stock was divided into four equal units — among Burroughs, Metcalf and investors R.M. Scruggs and W.R. Pye. Metcalf was chosen president, Burroughs vice-president and Scruggs treasurer.

By 1888, further improvements had been made and Burroughs was nearly ready to put his machine into production. By then, he was feeling pressure from the stockholders and Burroughs made the mistake of starting manufacturing before he felt the design was perfect.

By 1890, the first batch of machines was being purchased by businesses. When reports started coming in on their performance, they were uniformly bad and the firm had to recall all 50 that had been sold.

The trouble with the devices lay in the main crank. For numbers to be satisfactorily accumulated, the handle had to be pulled steadily forward and then released — in a smooth motion.

Never one to give up, Burroughs locked himself in his workroom for 72 hours and emerged only when he felt he had perfected a governor mechanism that would guarantee consistent performance of the machine, no matter how the operator yanked the lever.

His automatic governor, called a "dash pot," was a metal cup filled with oil in which a plunger worked to regulate the lever's movement.

As for the theory upon which the machine itself was designed, Burroughs was working in an era when key-driven machines were desirable, following the development of the typewriter in the early 1870s.

His design, however, called for the machine not to be driven by keys, but rather by a separate handle. The number was set on the keyboard, the pressed keys of which remained down to allow the operator to check the figure. When the handle was pulled, the number was added to the results register, as well as printed out.

One of the major problems was that of "carrying" when, for example, "1" was added to 999,999. This was a stumbling block that had tripped up many inventors of calculators.

But Burroughs solved the problem by making a separate column of identical keys for every decimal place, although a more compact machine could have been built using a 10-key keyboard. The smaller keyboard, however, would be vulnerable to errors made by pressing a key twice, or not hard enough, thus throwing off the calculation.

After seven years of constant toil and $300,000 spent, Burroughs had perfected the machine he always knew was possible. As if to close the door on his long, frustrating struggle, Burroughs one day committed an act for which he is perhaps more famous for than for all his inventiveness.

He entered the second floor storeroom where his 50 failed machines were kept, opened the window and deliberately hurled each and every one into the backyard, smashing them to pieces.

As the last crash sounded, Boyer entered the room. "There," Burroughs reportedly said, "I have ended the last of my troubles."

Although this dramatic action was undoubtedly satisfying, Burroughs was to discover his troubles were not quite over. He still had to sell his perfected Adding and Listing Machine.

Although Burroughs himself had not expected spectacular sales, he had figured that 8,000 machines — one to every U.S. bank — would saturate the market. As it turned out, in the first years the machines sold at a rate of one a week.

The early sales promotion campaigns were haphazard at best. One Burroughs representative in Albany, N.Y., is said to have vanished into thin air, together with his demonstration machine. He was eventually located in a bar, sitting next to a wheelbarrow, which held the machine.

Asked how sales were going, the representative claimed to have given Burroughs excellent publicly. There was not a bar for miles around where he had not been and in every one he had bet and won a drink on the machine's accuracy.

Such methods would not do. In 1895, the firm's three best salesmen sat down and divided the nation among them, into territories of just more than a million square miles in a week to sell a single machine for small profit on the $475 selling price.

Difficult as it must have been, the new sales policy created good will and proved successful. In a year sales went up to over 400 and two years later had topped 700.

With his dream realized, Burroughs retired to Citronelle, Ala., where he died on Sept. 14, 1898, after a long bout with tuberculosis. He was 41. On his burial place is a monument "Erected by his Associates as a Tribute to his Genius."

# *Growth of Statistics Spawns Invention*

A growing interest in social investigation had, by the second half of the 19th century, created a passion for the statistical method. Besides the eventually popular machines of Burroughs, other mechanical calculating inventions were springing up in America and abroad.

In 1850, the U.S. Patent Office issued a patent to D.D. Parmelee for a key-driven adding machine. He is said to have been the first to deviate from the use of numerical wheels, and in its place used a long ratchet-toothed bar. Parmelee also reportedly was the first to use depressible keys in a calculator.

Seven years later, Thomas Hill obtained a patent on a multiple-order key-driven calculator. While the device received a lot of attention, it had a fatal flaw. It failed to control the rotation of the numerical wheel under the tremendous speed that resulted from the use of depressible keys.

An alternative to Leibniz's historic stepped wheel was designed by Frank Stephen Baldwin in 1872 [Part 2]. Machines based on the design were made by W.T. Ohdner and the device became known as the Ohdner Wheel. Ohdner-type machines were widely used until the introduction of the electronic calculator in about 1960.

Inspired by the travails of C.X. Thomas [Part 2], Charles Babbage and George Scheutz [Part 3], the American George Bernard

Grant constructed a monstrous Difference Engine, which he exhibited — along with several other calculating devices — at the 1876 Philadelphia Centennial. Master of the mechanical gear, on which his inventions were based, Grant was one of the founders of the gear industry in the U.S.

It was Dorr Eugene Felt who next addressed the problem of the multiple-order key-driven calculating machine, in work that directly inspired Burroughs. In 1884, Felt conceived an idea from watching the ratchet feed motion, which was to lead to the mechanical basis for the modern calculator.

"I worked on the principle of duplicate denominational orders that could be stretched to any capacity within reason," Felt later recalled. While his idea for a calculator called for metal parts, the youthful Felt could not afford metal and settled for wood.

"I went to the grocer's and selected a box which seemed to me to be about the right size for the casing. It was a macaroni box, so I have always called it the macaroni box model," he explained. "For keys, I procured some meat skewers from the butcher around the corner and some staples from a hardware store for the key guides and an assortment of elastic bands to be used for springs.

"When Thanksgiving Day came, I got up early and went to work with a few tools, principally a jack knife." Felt eventually had to have some of the parts made of metal, and he finished his model by New Year's Day of 1885. At the age of 24 he had made the first operative multiple-order key-driven calculating machine.

Still with limited funds, Felt had to manufacture his first models himself. Between the fall of 1886 and the next autumn, he produced eight finished models. Soon he had demonstrated and placed models at the U.S. Treasury and the New York State Weather Bureau.

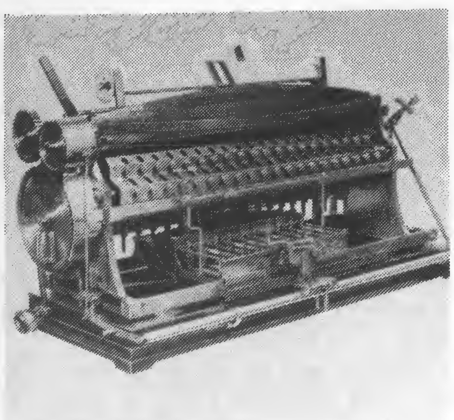
In November 1887, he formed a partnership with Robert Tarrant of Chicago. The burgeoning success of the "Comptometer" was so complete that until 1902 no other machine of its kind was put on the market.

A colorful French inventor, Leon Bollee — also the founder of the famous Le Mans racetrack — built a direct multiplication machine in 1889 when he was 19 years old. His family needed the device to help prepare extensive tables of bell dimensions for its foundry at Le Mans.

While his later years were devoted chiefly to designing, building and racing light automobiles, Bollee also invented other calculators and office machines. His life of invention had begun at the age of 13, when he patented an unsinkable aquatic bicycle. An Englishman named Rigby rode it across the English Channel.

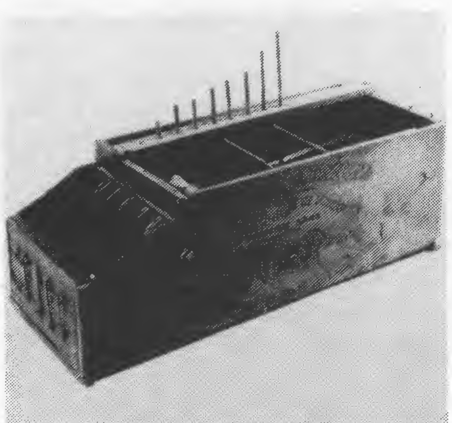
Building on Bollee's design, Otto Steiger of Zurich developed a machine in 1893 that used a mechanical "lookup" table, and was in effect an automated version of Napier's Bones [Part 1]. Although cumbersome, the machine was popular, especially in scientific calculation. Between 1894 and 1935, 4,655 of them were sold under the name "The Millionaire." From 1910 on, electrically operated versions were available.

Although Bollee and Ramon Verea had built machines according to the same principles, Steiger's was the first to be commercially successful. Verea was a Spaniard living in New York City. After he developed his machine in 1878, he told the *New York Herald* reporters that he "did not make the machine to either sell its patent or put it into use, but simply to show that it was possible and that a Spaniard can invent as well as an American."



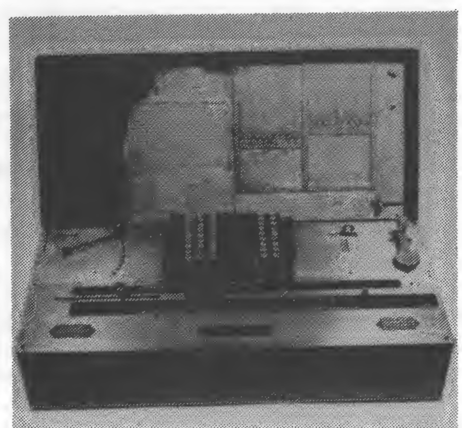
Courtesy IBM

**Bollee's Multiplication Machine**



Courtesy of IBM

**Felt's "Macaroni Box"**



Courtesy of IBM

**Steiger's "Millionaire"**

# Part 6 . . . Herman Hollerith: Punched Cards Come of Age

Courtesy IBM

*"The more things change, the more they remain the same."*

— Alphonse Karr (1849)

There is irony in the current delays surrounding issuance of the reports and computer tapes from the 1980 census — the most thorough dicennial enumeration in the nation's history.

A century ago, it was just such delays in the 1880 census that led to the use of punched cards in census taking — a giant-step innovation in the history of the census and of the electronic computer, which now tallies the census.

While the delays of 1880 stemmed from a lack of sophisticated technology, the delays of today are borne of the excesses of the technology that has finally come into its own.

A hundred years ago, thousands of human beings manually counted the census results of 1880. No matter that the workers were diligent; the task took seven and a half years, by which time the figures were close to useless.

During those seven and a half years, a young Census Bureau engineer, Herman Hollerith, attacked the problem of statistical tabulation. Through trial and error, diligence and a fateful conversation, Hollerith — echoing Charles Babbage's plans to use Jacquard-loom-inspired punched cards for the Analytical Engine — set in motion a technology that would change the world.

Herman Hollerith was born in Buffalo, New York, on Feb. 29, 1860, the son of German immigrants. The only noteworthy situation in his childhood was an immense dislike for spelling. It is said that, in an effort to avoid a spelling lesson, he once leaped from a second-story window and ran home. Hardly an illustrious beginning.

Nevertheless, Herman was gifted in other areas and finished his lower schooling under the disciplined tutelage of a Lutheran minister. Hollerith graduated from Columbia University's School of Mines in 1879 at the age of 19.

At Columbia, Hollerith's work had drawn the attention of one of his instructors, Professor William P. Trowbridge, who was also a chief special agent for the Census of 1880. Trowbridge recruited Hollerith for the Census, where he went to work in October of the year he graduated.

It was Hollerith's association with his superior at the Census, John Shaw Billings, that led directly to the idea for a punched card tabulator. Billings, an Assistant Surgeon in the U.S. Army, was a gifted administrator who had been sought out by the Census Office, although he never was on its payroll.

Billings was in charge of the work on vital statistics for both the 1880 and 1890 censuses — specifically, the collection and tabulation of the data. And it was Billings' suggestion to Hollerith that Jaccquard-like punched cards might be the answer to the massive tabulation problems of the Census.

As with so many significant events in history, there are two versions of how the seed of the idea was planted in Hollerith's mind. One has Billings and Hollerith strolling through the office where the 1880 returns were being manually tabulated by hundreds of clerks.

Billings reportedly said to Hollerith, "There ought to be some mechanical way of doing this job, something on the principle of the Jacquard loom, whereby holes in a card regulate the pattern to be woven."

Another version, written by Hollerith in 1919, has the two sitting at Billings' tea table on a Sunday evening, with Billings making the same suggestion.

Whatever the actual setting was, Hollerith later recalled, "after studying the problem I went back to Dr. Billings and said that I thought I could work out a solution for the problem and asked him if he would go in with me. The doctor said he was not interested any further than to see some solution of the problem worked out."

What does seem clear to all who have written about the incident is that Billings was the source of the idea and Hollerith the implementer. It would be a few more years, however, before the project would come to fruition.

In September, 1882, Hollerith temporarily took leave of the Census Bureau to accept an invitation to teach mechanical engineering at MIT. General Francis Walker, also from the Census Bureau, had become president of MIT and had extended the invitation.

"While at Boston I made some of my first crude experiments in tabulating machinery," Hollerith wrote. "My idea at that time was to use a strip of paper and punch the record for each individual in a line across the strip.

"Then I ran the strip over a drum and made contacts through the hole to operate the counters. This you see gave me an ideal automatic feed," he noted. "The trouble, however, was that if, for example, you wanted any statistics regarding chinamen you would have to run miles of paper to count a few chinamen."

(The reader must keep in mind that the times were oppressive for most minorities, and — right or wrong — Hollerith's use of "chinamen" would not have been generally disdained as it is today.)

Hollerith claimed that a major breakthrough in his work came from his observation of a train conductor, who hand-punched tickets to record basic descriptions of his passengers. Hollerith felt the same technique could be used to record the proper census statistics for each individual in the United States.

Hollerith continued his experimental work in St. Louis after a year of teaching at MIT. After a few months in St. Louis, he returned to government work in the summer of 1883, for the Patent Office — a short-lived position from which he resigned on March 31, 1884.

Devoting his efforts wholeheartedly to the construction of his statistical tabulating system, Hollerith within six months applied for a patent — on Sept. 23, 1884. Five years later, on Jan. 8, 1889, three more patents were issued to him. Hollerith eventually accumulated a total of 31 data processing patents.

In 1890, three major events happened in Hollerith's life: he married the daughter of Dr. Billings, he received his Doctorate of Philosophy from the School of Mines for his dissertation on "The Electric Tabulating System" and the U.S. conducted its eleventh census — using his system.

Before being awarded the contract for the 1890 census, Hollerith had competed with three other proposed systems, all of which took about eight times as long as Hollerith's to tabulate the results. In addition, Hollerith's was about twice as fast as his nearest rival in total time spent transcribing onto cards and tabulating.

The contract was an important factor in Hollerith's future financial success. And, as he characterized it, ". . . it was indeed a brave act on the part of [Census Superintendent Robert P.] Porter to award me a contract for the use of the machines in compiling the census. Where would he have been had I failed?"

Hollerith needn't have worried. Just one month after all the 1890 census returns arrived in Washington, the bureau announced the total population count of 62,622,250 on Dec. 12, 1890. Although the population of the country had grown from 50 million to 63 million since the 1880 census, the complete 1890 analysis was completed in two and a half years, one-third the time taken previously.

In an 1891 paper on the subject, Porter stated, "The Eleventh Census handled the records of 63,000,000 people and 150,000 minor civil divisions. One detail (characteristic) alone required the punching of one billion holes. Because the electrical tabulating system of Mr. Hollerith permitted easy counting, certain questions were asked for the first time. Examples of these were:

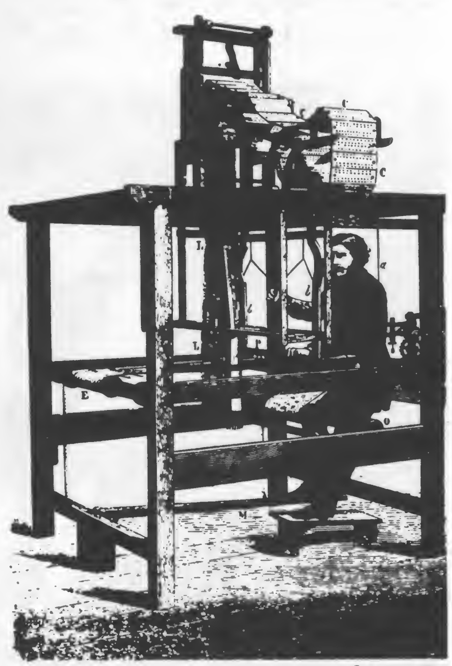
- Number of children born.
- Number of children living.
- Number of family speaking English.

"By use of the electric tabulating machine, it became possible to aggregate from the schedules all the information which appears in any way possible," Porter continued. "Heretofore such aggregations had been limited. With the machines, complex aggregations can be evolved at no more expense than the simple ones."

The *Electrical Engineer* had this to say: "This apparatus works unerringly as the mills of the gods, but beats them hollow as to speed" (Nov. 11, 1891).

Besides such verbal praise from all sides, Hollerith received several prizes for his invention. The Committee on Science and the Arts of the Franklin Institute of Philadelphia awarded him the Elliott Cresson Medal, its highest award. Of particular pride to him were the Paris Exposition Medaille d'Or and the Bronze Medal from the World's Fair of 1893.

What exactly was the system that revolutionized census-taking and eventually much, much more? As a refinement of his continuous paper strip, Hollerith decided to begin instead with separate cards on which clerks manually punched holes corresponding to certain characteristics



Courtesy IBM

**Sketch of Jacquard Loom Cards Guiding the Pattern on a Weave of Cloth About 1810 in Lyons, France.**

of the citizens who had been interviewed.

His first use of the system, for vital statistics for the city of Baltimore in 1887, made use of cards measuring 3¼-in. by 8⅝-in., with three rows of 32 punch positions across the top of the card and three rows across the bottom.

The card used for the 1890 census was two inches shorter, but the same width — corresponding to the size of the dollar bill — with punch positions occupying the whole surface of the card. Of the 24 columns of ¼-inch squares (288 in all), the four columns at the left were reserved for geographic identification.

One type of machine was used to punch the 240 spaces comprising the body of each card, and a second, known as the "gang punch," punched several cards at once, for the geographic identification section.

Once punched, the cards were read by placing them in a "pin press," which contained a mercury cup beneath each position where a hole might occur in a card. A hinged lid was closed, carrying a spring-loaded "pin' or plunger corresponding to each mercury cup.

If a hole had been punched, the pin passed through it to make electrical contact with the mercury in the cup below. If there was no hole, the card held the pin back and no contact was made. Between 50 and 80 cards a minute could be passed through the pin press.

Hollerith is said to have borrowed the electromechanical technology that had been developed in 1858 by Emile Baudot for the electric telegraph, and used electromechanical counters to count the number of cards with a particular perforation. The tabulator's 40 dials allowed the answers to several questions to be counted simultaneously.

To avoid false counts or skipping an incorrectly punched card, the circuits were arranged to ring a bell each time a counter registered a card. The cards that did not ring the bell were laid aside for further investigation.

An electromagnetically controlled sorting slot separated selected cards.

The sorter had a box containing 24 bins, each with a lid held closed by an electromagnetic latch working against a spring. When a hole was sensed, an electric current flowed that turned off the latch, allowing the spring to open the lid. The card was then dropped into the open bin by hand.

At the end of each day, the total on each of the 40 dials was recorded by hand and the dial was set back to zero.

A crucial ability of the system was that of sorting numbers of cards according to a given characteristic. In a few sorts one could determine, for example, how many people out of a northern population were white.

The machine was extremely reliable, although there were occasional mechanical failures. However, in the words of one operator: "The trouble was usually that somebody had extracted the mercury from one of the little cups with an eye dropper and squirted it into a spittoon, just to get unneeded rest."

Recognizing the commercial value of his invention, Hollerith set up the Tabulating Machine Co. in 1896 and manufactured both machines and cards at its first plant in the Georgetown section of Washington, D.C.

The results of the American experience impressed the world and it was not long before Hollerith's system was being used in Canada and Austria and being tried out in Italy, France and Germany. Hollerith even managed to get a contract with Russia for its first census, taken in 1897.

His equipment was used again for the twelfth U.S. Census in 1900, this time on a rental basis. During the 1900 census, Hollerith developed an automatic tabulating mechine, into which cards were fed automatically rather than by hand.

Also during the 1900 census, Hollerith turned his attention to the statistics of agriculture, soon realizing that a faster method of sorting was required to keep ahead of the tabulating machines. Rising to the challenge, Hollerith devised the first electric sorting machine.

In spite of his innovations, it was during the 1900 census that Hollerith's relationship with the Census Bureau deteriorated; it would be his last census. One portent came when Agriculture Chief Dr. L.G. Powers charged that the Hollerith equipment had resulted in the census costing twice as much as it would have using hand work and adding machines.

Then in 1903, S.N.D. North became the first Director of the Census, following passage of the Permanent Census Bureau Act. It was not long before North and Hollerith had a disagreement over the rental charges for Hollerith's machines.

North was determined to improve Hollerith's equipment — independently. He received a $40,000 Congressional appropriation, set up the Census Machine Shop and hired as its director an obscure statistical engineer from New Jersey.

James Powers was the engineer and he proved to be an excellent choice. Under his leadership, the laboratory

Courtesy Carpenter Center for the Visual Arts, Harvard University

**Ellis Island immigrants circa 1890. The influx of Europeans into the U.S. caused a 13 million jump in population between 1880 and 1890.**

produced several refinements of Hollerith's machine. One feature was counters that automatically recorded the tallies, eliminating the need to manually read the dial faces.

Powers' approach differed from Hollerith's in that he wanted to build mechanical, rather than electromechanical, machines. In 1908, he introduced the "simultaneous punching" concept in which all the data to be placed on a 20-column card was entered on a keyboard, then, by pressing a punch key, the operator punched all the holes at once.

This guaranteed that partially punched cards could not enter the system and also allowed operators to check the data before operating the punch. Powers also developed mechanical sorters and tabulators that proved very reliable.

So pleased was North with Powers' accomplishments that he purchased 300 punches and related sorters and tabulators for the 1910 census. Soon after, Powers — who had retained the right to patent any machine he developed — left the census and in 1911 formed the Powers Accounting Machine Co., which became the census' major source of equipment.

Years later, Hollerith expressed his disappontment: "I always have regretted that I could not stay in census work long enough to carry out my ideas regarding verification machines."

Hollerith did, however, branch out into other markets for his equipment. His machines were used, for example, by the New York Central and Long Island railroads to audit freight statistics, a method that came to be adopted by other railroads.

A large machine tool manufacturer, in a portentous application, used Hollerith's tabulating machine to compile costs, analyze the payroll and keep track of materials in order to carry a perpetual inventory.

A wholesale house with eight departments carrying 33 classes and 170 subclasses of merchandise used the systems to get classified information on sales, including source, salesman, kind of merchandise, cost and selling price, salesmen's commissions, individual customer, territory and other factors adding to a firm's gross profit.

In addition, a fire insurance company — using the system for analysis and classification work — was able to determine amounts at risk, premiums received and losses paid on its several hundred classes of insurance.

Hollerith's last involvement with the census bureau was in the form of a law suit filed by the Tabulating Machine Co. in 1910 against the agency, claiming that, in remodeling the Powers machines, the Census had infringed on some of Hollerith's patents. The suit was disposed of without significant action.

In 1911 — the year Powers Accounting Machine Co. formed — Hollerith's 15-year-old Tabulating Machine Co. merged with the International Time Recording Co., the Dayton Scale Co. and the Bundy Manufacturing Corp. to form the Computing - Tabulating - Recording Co. (CTR).

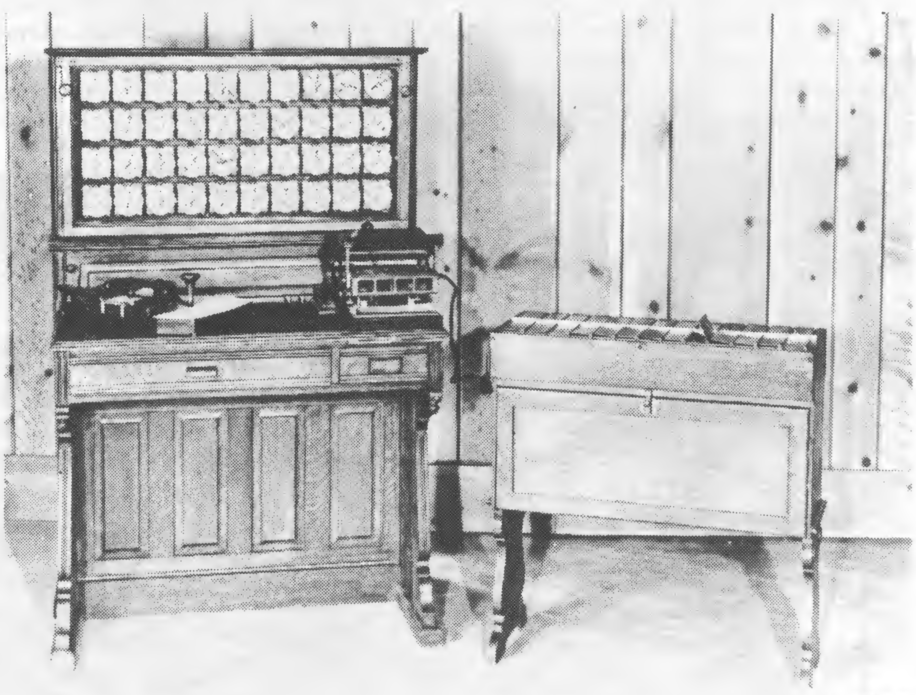
The CTR Co., a holding company, was renamed the International Business Machines Corp. in 1924. In 1933, IBM was reorganized and became an operating corporation.

In 1927 the Powers Accounting Machine Co., through a series of business consolidations, became the Tabulating Machines Division of the Remington-Rand Corp., which in 1955 merged with Sperry Gyroscope to form the Sperry-Rand Corp.

While one might have expected Hollerith's and Powers' firms to remain competitive for many years, it is doubtful that many could have foreseen just how gigantic each was to become. The companies started by two punch-card pioneers would evolve into two of the most significant computer manufacturers from 1950 on.

Hollerith, who received his last patent in 1919, remained associated with CTR until 1921. Even in 1923, he wrote of plans to develop a tabulator, similar to those later in use. Unfortunately, illness did not allow Hollerith to realize his plans.

On Nov. 17, 1929, in Washington, D.C., a heart attack took the life of Herman Hollerith at the age of 69. His time-saving contribution to statistical tabulation — still in use today — helped revolutionize the world we live in.



Courtesy IBM

**Hollerith Tabulating Machine**

Courtesy of IBM

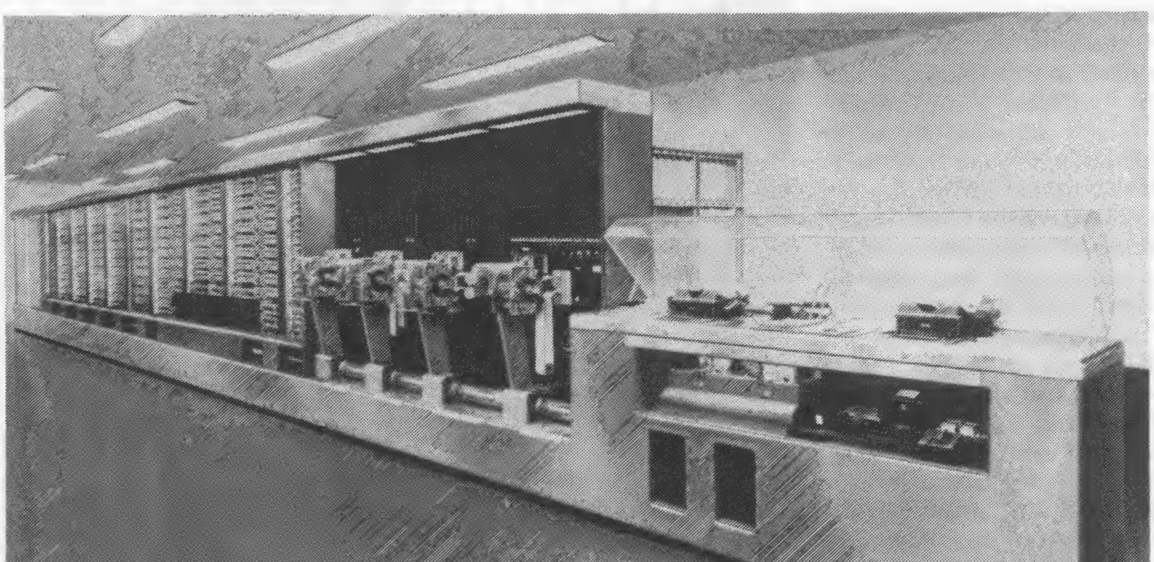
# Part 7 . . . Thomas J. Watson Sr.: The Businessman's Businessman

Rarely has one man had such a God-like influence over a business entity as did Thomas J. Watson, Sr., for 40 years the inspiration, leader and partriarch of IBM Corp.

The acknowledged leader of the computer industry for almost three decades, IBM owes its success largely to the tastes, beliefs and ideals of Watson, who almost single-handedly elevated his company to a level rivaling that of organized religion.

Indeed, IBM in its early days was infused with a decidedly religious tone, featuring fervent revival meeting-type conventions, group singing, inspirational slogans and the ever-present (benevolent but unpredictable) father figure of Watson, overseeing his carefully groomed universe.

Watson became so influential, in fact, that he not only enjoyed close relationships with three American presidents, but entertained the most important political and social figures in the world.



Courtesy of IBM

**IBM's first computer — the Mark I.**

How did he do it? How did a backwoods peddler from Painted Post, N.Y., grow to build an empire that today — 25 years after his death — has installations and operations in over 100 countries and employs over a quarter of a million people?

The answer lies in Watson's strong personality, high ideals, his ability to learn from others and his ability to learn from his own mistakes. On a road that was not always smooth, Watson repeatedly turned the most discouraging circumstances into opportunities through his ingenuity and remarkably strong force of will.

The story begins simply enough, with the birth of Thomas John Wasson on Feb. 17, 1874, to a brawny, tough lumberjack and his wife. "Wasson" was a permutation of the original family name, "Watson," from Scotland and Ireland. When a family member married a Catholic and settled in Brooklyn, N.Y., the rest of the family attempted to disassociate itself from Catholicism by changing its name en masse.

It was Tom's father who, after 30 years of being a Wasson, decided to conform to the surname tattooed on his arm and again became a Watson, as did the rest of his household.

Young Watson's childhood was largely uneventful. Neither studious nor athletic, he reportedly was lively and assertive, with a quick temper that was to plague him all his life. He spent much time helping to run the family farm: training horses, harvesting and topping trees.

As his own son, Thomas J. Watson, Jr., would later say: "He grew up in an ordinary, but happy, home where the means, and perhaps the wants, were modest and the moral environment strict. The important values, as he learned them, were to do every job well, to treat all people with dignity and respect, to appear neatly dressed, to be clean and forthright, to be eternally optimistic, and above all, loyal."

Not only would Watson retain those same values throughout his entire life, but he would see them successfully instilled in thousands of his own workers during the nearly half a century that he held the corporate reins at IBM.

His father, with little formal education himself, held high ambitions for his son and advised him to become a lawyer. Young Watson, however, tended toward a teaching career and tested the waters by becoming a substitute teacher.

Legend has it that it took merely one day for Watson to make up his mind. At the end of that day, he concluded, "That settles my teaching career. I can't go into a schoolroom with a bunch of children at nine o'clock in the morning and stay 'til four."

Watson's next alternative proved to be a truer love: he would go into business. After a year at the Miller School of Commerce in Elmira, N.Y., studying accounting and business, Watson landed a job as a bookkeeper in a meat market.

The year was 1892 and his salary was six dollars a week. Although the money was considered good, the challenge was less than compelling. "I couldn't sit on a high stool and keep books all my life," he commented.

Fate was to come to Tom Watson's rescue in the person of George Cornwell, a traveling salesman who dealt in pianos, organs and sewing machines. Cornwell offered Watson a job as his assistant at $10 a week, provided he could supply his own horses to pull the wagon.

Thus began a spirited adventure through country fairs and dozens of small villages that was to remain one of the fondest memories of Watson throughout his long and distinguished career. The open road cast its spell on Watson and he would never cease to be a traveler.

When Cornwell left the company, Watson got his territory, "and that was the most responsible job I've ever had from that day to this," Watson recalled many years later. "And I felt more important in it than any position I've ever held, because I was the general manager, sales manager, accountant, deliveryman — I was the whole organization."

By 1894, Watson's father, whose own farming enterprise had been plagued with bad luck and natural disaster, counseled his only son to


Courtesy IBM

**Early IBM factory, circa 1925.**

Courtesy IBM

**The Columbia University Statistical Bureau, begun in 1928 with three truck-loads of loaned IBM tabulating equipment.**

leave Painted Post. While he might make a living there, it was no place to spend a lifetime, he felt.

So, on to Buffalo went Tom. There he found a short-lived job selling sewing machines, followed by a job with the Buffalo Building and Loan Association selling stock to the public to finance the company's growth.

While arranging a transaction for Buffalo Building and Loan at the office of the National Cash Register (NCR) Co., Watson applied for a position as salesman. It took several attempts, but finally Watson convinced manager John J. Range to hire him, in October 1895.

Watson found himself face-to-face with the country's first canned sales approach, as presented in the NCR Primer. The brainchild of NCR president John H. Patterson, the sales pitch had been adopted in 1887 and comprised a word-for-word transcript of the pitch used by the company's best money earner at the time.

Watson at first had absolutely no luck selling cash registers. After Watson had worked 10 days without a sale, Range lit into the young man with a harsh speech designed to open his eyes to the realities of selling.

Open his eyes it did, and just when Watson had decided he would quit his job at the end of Range's speech, the tone of the tirade changed completely, and Range suggested the two of them go out together and try again to sell some machines.

Watson's experience with Range taught him two major things. From him Watson learned his devastating technique of "ripping a man apart and sewing him up again," as Watson called it, and he also learned to sell.

Four years later, at the age of 25, Watson was promoted to manager in Rochester, N.Y. "The reason I was given that territory was that nobody else would take it," he claimed. But Watson did take it and from there began his dramatic climb to the heights of the business world.

In 1903, Watson's reputation was solid enough so that he was chosen over 400 other salesmen at NCR to head a new, secret subsidiary. Selected partly because of his very obscurity, Watson was now slated to mastermind the feat of gaining control of all the secondhand cash register business in the country.

It was NCR's success in producing long-lasting machines that led to the disturbing situation of competitors making a profit selling NCR products. The plan now was to launch a well-financed, well-organized frontal attack on those operations. No one was to know of its connection with NCR.

Seeing the enterprise as a personal opportunity, Watson took on the assignment with enthusiasm and soon proved his talents as an executive. Falling to his cutthroat assignment, Watson established stores next to successful competitors, copied their successes and discarded their unsuccessful methods, undersold them, hired their salesmen away from them and eventually put them out of business.

It is said that Watson always regretted his experiences during those years and rarely mentioned them. On the other hand, his tactics were as fair as they could be under the circumstances. He always treated his competitors with consideration and offered generous settlements, often even hiring the bereft businessman as well as buying him out.

By 1907, the secret was out and NCR announced that Watson was in charge of the secondhand business of the company. Now the third most powerful man at NCR, Watson was 33 years old.

Patterson soon displayed his notorious flamboyance in a gesture meant to show his appreciation of Watson's years of dedicated hard work. During a visit to Watson in his hotel room, Patterson commented, "I don't think this is the address you ought to have. I'm going to build you a house."

Build Watson a house he did and would not accept rent payments. Furthermore, Patterson soon furnished Watson with a classy Pierce-Arrow car.

In the midst of Watson's material good fortune, he met the woman who would stand by him through thick and thin, the beautiful, well-bred Jeannette Kittredge, daughter of a successful Ohio businessman.

Watson was 38 and Jeannette 29 when they met in the spring of 1912. A year later they were married. As a wedding gift, Patterson presented them with a summer house especially built near his own summer home. Less than six months later Patterson would fire Watson.

Watson was one in a long line of distinguished men whom Patterson fired. The president was known to cultivate strong, intelligent advisors until they reached a point where Patterson felt they were overstepping their bounds. The end was swift and often severe, as in the case of one executive who returned from a trip to find his desk and chair in flames outside the factory.

Watson's end at NCR was not quite as dramatic and ended a period of months during which the two men's relationship grew more and more difficult. Patterson reportedly grew increasingly envious of Watson's popularity with the sales force, but the final catalyst was a disagreement over company policy.

Not only did Watson diagree with a proposed policy of Patterson's, but he disagreed with Patterson in front of other company executives. Suddendly, Watson's access to Patterson was reduced to almost nothing and within weeks Watson got the word that he was no longer wanted.

Three months short of 40 and two months short of fatherhood, Watson was without a job. As he left his NCR office for the last time, he reportedly said, "I've helped build all but one of those buildings. Now I am going to build a business bigger than John H. Patterson has."

Deluged with job offers from successful companies wanting to pay him a large salary for his proven abilities, Watson instead wanted to assume leadership of a company, work only for a commission and share in the firm's profits.

Watson found the perfect environment for his talents in the newly formed Computing-Tabulating-Recording Co. (CTR), a result of the merging of Herman Hollerith's Tabulating Machine Co., International Time Recording Co., the Dayton Scale Co. and Bundy Manufacturing Co. [Part 6].

Watson started at CTR in 1914 with a yearly salary of $25,000 and an option on 1,220 shares of stock. After three months, Watson was president; his principal goal was to bring CTR to a position of technical advancement in the face of a growing need for automatic calculation.

With Hollerith losing interest in technical innovation as he felt company control slip from his hands, Watson recognized the need to forge ahead with research and development, especially in light of superior equipment being produced by inventor James Powers' Powers Accounting Co.

Powers reportedly had a statistical machine that printed results as opposed to Hollerith's hand-posting, featured an electrical punch instead of Hollerith's hand-operated one, and a horizontal sorter in place of the inconvenient vertical sorter Hollerith had designed for crowded railroad offices. Worse yet, Powers rented machines for $100 per month while CTR asked $150.

In October, 1914, Watson established a research department under one of Hollerith's men, followed two years later by a laboratory. It was there that engineer Clair D. Lake invented a superior printer-lister that saved the Tabulating Machine Co. from ruin.

At the first combined sales meeting of the CTR, in 1919, Watson dramatically unveiled the machine and, with the flick of a switch, the device began printing results as cards flowed through it. Salesmen stood up in their chairs and cheered, feeling they were at the gateway to commercial success at last.

And they were. The Tabulating Machine Company was to revolutionize its industry in a move from accounting to data processing and global communications and in the forefront of a technology that great men of all centuries had dreamed of but been unable to achieve.

Six years after Watson joined the company, CTR's gross income had more than tripled from $4 million to almost $14 million. The year 1920 saw the firm doing more business than it had done in the previous four years combined.

In spite of a recession in 1921, the company carried on — largely because of the faith and money extended by the Guaranty Trust Co. By 1924, stockholders were receiving dividends three times greater than in 1913 and the market value of the stock was more than five times its earlier worth.

In 1924, Watson became chief executive officer of the company and its name became International Business Machines — "International" to suggest the projected scope of its influence and "Business Machines" to indicate the diversity of its interests.

Watson was now completely in charge and began a campaign to impress his distinctive personality on the organization. Watson felt that his workers should exhibit loyalty, unity, idealism, enthusiasm and spiritual commitment. "You have to put your heart in the business and the business in your heart," he said.

The extreme loyalty Watson extracted from his men became known as the "family spirit" and if anyone felt a bit too put upon by the emotional demands of a paternalistic chief executive officer, out the door he went. Those who left walked away from a religiously nonunion company that offered its employees a country club, educational programs and gala celebrations that stemmed from Watson's love for ceremony, luxury and impressive outward appearances.

During the Depression Years of the 1930s, Watson was victor instead of victim. Although the office equipment industry suffered a 50% decline at that time, IBM held steady.

Instead of laying off large numbers of workers, he continued his building program and churned out more equipment to be stored for future use. In 1935, when the newly created Social Security System cast about for someone to do its bookkeeping, it was IBM's huge surplus that guaranteed it the contract.

Other New Deal agencies and social changes helped make IBM into a veritable giant. Legislation was being passed requiring very detailed recordkeeping in every phase of business and government. In the last half of the 30s, the income from IBM's electrical accounting machines doubled. By 1940, the firm was doing more business than any other office equipment company. Its course was set.

Watson's involvement with New Deal contracts led him closer and closer to Washington, D.C. As well as defending business interests to the Roosevelt administration, Watson spoke well of FDR's New Deal to the business community.

For his support, Roosevelt offered Watson the ambassadorship to Great Britain and the office of Secretary of Commerce, both of which Watson declined. Watson did, however, turn his attention to building up a European organization for IBM. His efforts would culminate in the organization of IBM's World Trade Corp. in 1949.

"World Peace Through World Trade" became IBM's slogan. As president of the International Chamber of Commerce, Watson became so well-known through his speechmaking that many foreign subsidiaries were named Watson Business Machines.

When World War II hostilities began in Europe, Watson put all the IBM facilities at the government's disposal. Besides performing accounting tasks arising from the war, IBM factories actually produced rifles and rifle parts as well as parts for aircraft engines. For his cooperation with government objectives, Watson received the Medal of Merit.

It was during the war that IBM entered the computer business, largely in response to the innovative ideas and financial needs of the inventor Howard Aiken, then at Harvard University.

Aiken, like previous computer pioneers, was concerned with the vast amounts of calculations necessitated by science, technology and government. After reading the original works of Charles Babbage concerning his theoretical Analytical Engine [Part 3], Aiken wondered whether existing calculators could be combined into one super calculating machine.

Specifically, Aiken wondered about IBM's highly successful 601 Multipliers, but soon concluded that any such project would have to start from the ground up as opposed to resulting from the combination of several existing machines.

Approaching IBM's extremely respected inventor James Bryce, Aiken broached the possibility of such a project. Upon Bryce's presentation of the idea to Watson, whose faith in science and technology was boundless, $500,000 was made available for development work.

The war threatened to stop the project before it began, but when the Navy — in which Aiken was a lieutenant — realized the value of such a device to naval problems, Aiken was released on detachment to complete the work. IBM assigned an engineering team led by Clair Lake to help Aiken and the project was under way.

Five years later, in 1944, the Automatic Sequence Controlled Calculator — familiarly known as the Mark I — was unveiled. Measuring 51 feet long and eight feet high, the Mark I contained about 800,000 parts and offered 60 registers for constants, 72 storage registers for addition, a central multiplication and division unit and could compute elementary transcendental functions such as logarithms and sine. It contained over 500 miles of wire.

The device could handle 23-decimal-digit numbers and perform additions in .3 second and multiplications in three seconds. One and a half minutes were needed to determine a logarithm to 20 decimal places.

Considering his accomplishment "Babbage's dream come true," which it certainly was, Aiken made an unfortunate misjudgment in taking full credit for its development. On the eve of the presentation ceremony, Aiken is said to have introduced the Mark I to the press without acknowledging Watson's and IBM's part in its development.

As a man who enjoyed getting the credit due him, Watson was enraged by Aiken's action. "I'm just sick about the whole thing," he reportedly said. And to Aiken he stormed, "You can't put IBM on as a postscript. I think about IBM just as you Harvard fellows do about your university."

In a bid for revenge and an attempt to eclipse the Mark I, Watson ordered his engineers to come up with a stunning machine. Before they could do that, however, the first fully operational electronic computer was developed at the University of Pennsylvania, in 1946.

The Eniac machine was revolutionary, featuring speeds and flexibility far beyond those of the previous electromechanical devices. IBM rose to the challenge and in 1948 introduced the Selective Sequence Electronic Calculator (SSEC).

The Korean War and the competition, principally from Remington-Rand's Univac computer — delivered to the Census Bureau in 1951 — drove IBM to produce its Model 701, a scientific computer 25 times faster than the SSEC.

Shortly thereafter, IBM offered the 702, 704 and 705 models, which were so popular that competition began to fall away and the firm was on its way to becoming the leader in the computer industry.

In 1952, Thomas J. Watson, Jr. became IBM's president and one week later, the government filed antitrust charges against the company. After three years of negotiations, Tom, Jr. — much against his father's desires — signed a consent decree for the Justice Department.

A bit reluctantly, but recognizing the leadership consistently shown by Tom, Jr., his father on May 8, 1956, gave over the position of chief executive officer to his son. On June 19, just over a month later, Tom Watson, Sr. died of a heart attack at the age of 82.

In the 40 years between 1914 and 1953, IBM had seen assets increase by a factor of 24, employees by 34 and data processing business by 316. Development expenditures had increased over 500 times, manufacturing space had mushroomed and the educational program that began with impromptu talks had evolved into an annual program costing $50 million.

"Our greatest assets are men," Watson had always said. And of him, when he died, his minister said, "Integrity was the root of his character."

# Part 8. . .
# Alan M. Turing: From Theory To Reality


Courtesy Digital Computer Museum

When the history of computing enters the modern era, we begin to see the integration of ancient, disparate threads of theory and experimentation to produce a workable, practical computing machine.

In the Nineteenth Century, Lady Lovelace, "the first programmer," had suggested that, in automatic computing, a large calculation might contain many repetitions of the same sequence of instructions [Part 3].

A century later, in 1936, the British mathematician and logician Alan M. Turing extended and updated her ideas with the publication of one of the single most important papers in computer science, "On Computable Numbers With an Application to the Entscheidungsproblem."

Besides expanding on Lovelace's work, Turing theorized on a machine that would also have delighted the Seventeenth Century philosopher Gottfried Leibniz [Part 2], who foresaw "a general method in which all truths of the reason would be reduced to a kind of calculation."

In his 1936 paper, Turing specified a completely abstract, theoretical computer that could do any calculation a human could do. The "Universal Turing Machine" featured many aspects that were later incorporated into all general computing machines.

Turing himself later took the opportunity to bring his ideas to life through his seminal work on what are generally regarded as the world's first working electronic digital computers, developed by Britain during World War II.

By all accounts, Alan Mathison Turing was an eccentric genius who generally maintained a cool, detached exterior among acquaintances, but who was truly a warm, caring person to those who knew him well.

Born in London on June 23, 1912 to upper-middle-class, well-educated parents, Alan showed his brilliance early. Around his third birthday, his mother wrote to his father, who was frequently absent on business, that Alan was "a very clever child, I should say, with a wonderful memory for new words. Alan generally speaks correctly and well. He has rather a delightful phrase, 'for so many morrows,' which we think means 'for a long time,' and is used with reference to past or future."

At the age of eight, his interest in science just blooming, Alan wrote a succinct treatise, "About a Microscope," which began and ended with: "First you must see that the lite is rite."

By the next year, however, Alan's scientific mind was much more sophisticated. He is said to have startled his mother, out of the blue, with the question, "Mother, what makes the oxygen fit so tightly into the hydrogen to produce water?"

In prep school, Alan looked upon sports as a waste of time, although years later he would become a first-class marathon runner. He noted, in retrospect, that it was during his early school years that he learned to run fast — he was always racing to get away from the ball.

At the end of the school year, his classmates joked about his interest in sports:

*"Turing's fond of the football field*
*For geometric problems the touch lines yield."*

For Christmas, 1924, Alan received a chemistry set and immediately began experimenting in the cellar of his home. Much of his effort went toward trying to extract iodine from seaweed from the local beaches.

At 12, he wrote his mother: "I always seem to want to make things from the thing that is commonest in nature and with the least waste of energy."

Obviously precocious, Alan soon received formal recognition of his gifts in the form of the Kirby Mathematics Prize — after his first term at the prestigious Sherborne School — followed by the Plumptre Prize for mathematics.

His mathematics instructor wrote that Alan was "a mathematician, I think." Not yet 15, Alan had evolved the calculus term, "tan $^{-1}$x," without any knowledge of calculus.

In 1930 and 1931 Alan won the newly created Christopher Morcom Prize for Natural Science, named after his best friend at Sherborne who had died in 1930. The prizes meant a great deal to Alan because of that friendship and in a letter to his mother he demonstrated the depth of feeling of which he was capable:

"I feel that I shall meet Morcom again, somewhere and that there will be some work for us to do together, as I believed there was for us to do here. Now that I am left to do it alone, I must not let him down, but put as much energy into it, if not as much interest, as if he were still here. If I succeed I shall be more fit to enjoy his company than I am now . . . It never seems to have occurred to me to make other friends besides Morcom, he made everyone seem so ordinary."

Besides the Morcom Prize, Alan won the Westcott House Goodman scholarship and the King Edward VI Gold Medal for mathematics. Upon his graduation from Sherborne, his head master described Alan as "a gifted and distinguished boy . . . Mathematicians and scientists one is apt to regard as being soulless creatures; but Alan is not, he is warm-hearted and has a savoring humor. We shall miss him, for he was a character and won respect."

And a character he was. At Cambridge, Turing did things in most unorthodox ways. To determine the correct time when setting his watch, Alan would not simply ask a friend the hour, but rather was known to observe a specific star, as seen from a definite place, and mentally calculate the correct time.

His complex ways of doing potentially simple things was a good indication of Turing's mental sophistication. Conclusive proof of his brilliance came in 1936, when at the age of 24 he wrote his paper, "On Computable Numbers."

In a letter to his mother explaining that the paper would be published that fall in the *Proceedings* of the London Mathematical Society, he explained that it was significantly different from one on the same subject just published by Alonzo Church, who taught at Princeton University.

It was Church's presence at Princeton that convinced Turing, "I have decided quite definitely about going there" for graduate studies. Once at Princeton, Turing wrote home, "The mathematics department here comes fully up to expectations. There is a great number of the most distinguished mathematicians here, [John] Von Neumann, Weyl, Courant, Hardy, Einstein, Lefschetz, as well as hosts of smaller fry."

Turing's paper, now considered one of the most important contributions to computing theory, presented a crucial theorem in mathematical logic in terms of an idealized computing machine.

Turing, however, was not the only mathematician to evolve a theoretical, abstract computing device. As often occurs with scientific breakthroughs, a second person simultaneously and independently arrived at the same conclusions.

Emil L. Post, a professor at City College of New York, published a paper in *The Journal of Symbolic Logic*, also in the fall of 1936, on "Finite Combinatory Processes — Formulation 1."

In that paper, Post suggested a computation scheme by which a "worker" can solve all problems in symbolic logic by performing only machine-like "primitive acts." It is remarkable that the instructions given to the "worker" in Post's paper and to a Universal Turing Machine were identical.

Turing, however, was in the right place at the right time. It is likely that his association with Princeton's Von Neumann — another brilliant pioneer in computing — ensured the prominence of his contributions. Von Neumann apparently was not aware of Post's work.

Von Neumann, often credited with developing the stored program concept, took a deep interest in the ideas of Turing and later extended them in his own work.

The Turing-Post theoretical digital computer was described as having an arbitrarily long tape running through the machine. The tape was divided into squares, on each of which was a one or a zero.

The machine would scan the tape one square at a time and sometimes alter what was on the tape by changing a zero to a one or a one to a zero.

Consisting of a collection of stored instructions, the machine could scan a square and choose its next instruction. It could also move the tape forward or backward by one square.

Such machines could perform a variety of calculations and Turing was able to prove several theorems about them. First, he proved that in the mathematical sense there must exist "universal" Turing Machines.

Universal Turing Machines are Turing Machines that can be programmed to do any computation or logical operation that any other Turing Machine can do. In other words, a Universal Turing Machine can be programmed to imitate any other Turing Machine.

Secondly, Turing showed that, even when given a "fixed and definite process" for solving a set of problems, some of those problems still cannot be solved. This was contrary to the prevailing views of the well-known mathematician David Hilbert.

An example of Turing's theory is shown by the so-called "Halting Problem," which addresses the question of whether a given Turing Machine with a given tape will ever stop computing or whether it will continue indefinitely.

Turing showed that there must exist at least one Turing Machine for which this question is, in principle, undecidable. One cannot devise a program to determine whether or not the machine will stop computing, according to Turing.

Turing's conclusion was a variation on a theorem proved in 1931 by Professor Kurt Godel of the Institute for Advanced Study. Godel's theorem showed that in a logical system as rich as arithmetic there must be at least one propostion whose truth or falsity is undecidable.

While some have regarded Turing's findings as proof that human intelligence is superior to machine intelligence, Turing in the mid-1940s replied to those points in his essay, "Can a Machine Think?"

"Whenever one of these machines is asked the appropriate critical question and gives a definite answer, we know that this answer must be wrong, and this gives us a certain feeling of superiority. Is this feeling illusory? It is no doubt quite genuine, but I do not think too much importance should be attached to it. We too often give wrong answers to questions ourselves to be justified in being very pleased at such evidence of fallibility on the part of the machines. Further, our superiority can only be felt on such an occasion in relation to the one machine over which we have scored our petty triumph. There would be no question of triumphing simultaneously over all machines. In short then, there might be men cleverer than any given machine, but, then again, there might be other machines cleverer again, and so on."

After receiving his doctorate from Princeton in May 1938 for his thesis, "System of Logic Based on Ordinals," Turing was offered a post as Von Neumann's assistant at the Institute for Advanced Studies. Turing instead accepted a fellowship at King's College, Cambridge, in his beloved England. He was then 26.

Turing was a major force in the early British effort toward digital computing, which was made all the more urgent by the pressing needs of World War II. By early 1940, Hitler had a firm grip on Europe and Britain lived under the cloud of possible invasion.

The British government recruited a team of the best mathematicians and electronics experts known and housed them in a serene-looking country house in Hertfordshire known as Bletchley Park. The scientists, among them Turing, were ordered to develop machines for cryptanalysis in an effort to keep a jump on Germany's military moves.

The Polish secret service had already captured the Germans newest code machine, Enigma, and shipped it to England. It was at Bletchley Park that Enigma's secrets were revealed through the use of what are now considered the first working electronic computers.

Turing was involved in the design of that series, which began with several electromagnetic machines using telephone-type relays of the kind used in Howard Aiken's Mark I computer [Part 7].

The electromagnetic machines were humorously nicknamed Heath Robinson (after the 1930s cartoonist reminiscent of Rube Goldberg), Peter Robinson, the Robinson and Cleaver (both named after London stores) and the Super Robinson.

The machines were truly effective and impressive since they could scan characters on paper tape through a photoelectric reader at the rate of 2,000 per second. Adequate today, that rate was virtually unheard of at the time.

From the Robinson series the team evolved a series called Colossus, which employed vacuum tubes instead of the relatively slow relays. Two thousand tubes did the computing and the paper tape input rate was pushed up to 5,000 char./sec, an even more outrageous speed.

The first Colossus was followed quickly by nine others before the war ended. While the Colossus series comprised the world's first electronic digital computers, and their capabilities far exceeded those of the contemporary Harvard Mark I in the U.S., they were special-purpose machines, dedicated solely to code cracking and not easily modifiable to any other purpose.

For that reason, they could not be considered a fulfillment of Babbage's dream of an Analytical Engine, while Aiken's Mark I was distinctly that.

Nevertheless, many people believe Colossus won the war for the Allies. The Germans reportedly had such faith in their Enigma machine that they simply used it throughout the war, mistakenly believing their telecommunications messages were inviolate.

Turing, in fact, was made an officer of the British Empire at the end of the war for his contributions toward victory.

With the war over, Turing was, as always, in great demand. Cambridge University offered him a lectureship, but he was more interested in testing out his 1936 theory and trying to build his own computer.

He presented a proposal to the government and joined the staff of the National Physical Laboratory in Teddington, England, becoming a permanent member of the Scientific Civil Service in October 1945.

At Teddington, John R. Womersley was head of the Mathematical Division. He had just returned from the Moore School of Electrical Engineering at the University of Pennsylvania, where work on the Electronic Numerical Integrator and Calculator (Eniac) was nearing completion.

Womersley brought the knowledge he had gained in the U.S., as well as Harry D. Huskey — who had written the engineering manual for Eniac — back to England with him to work on developing another computer.

As the Senior Principal Scientific Officer for the project, Turing reportedly "threw himself into the work with enthusiasm, thoroughly enjoying the alternation of abstract questions of design with practical engineering."

By November 1946, plans were nearing completion for construction of the Automatic Calculating Engine (ACE) Pilot (so-called to distinguish it from a larger ACE completed eight years later).

Demonstrated publicly in 1950, after Turing had already left Teddington, the ACE Pilot had storage capacity for 512 words of 32 bits in a mercury delay line, an addition time of 32 microseconds and a multiply time of about one millisecond.

Designed for reliability, the ACE Pilot contained only 1,000 vacuum tubes. To store program instructions, the machine used the "two-address method," in which each instruction also contained the position in the store (its "address") where the next instruction had been placed. Therefore the program was not in sequence, but might be dotted randomly all over the store.

While delay-line storage was advantageous because of the small number of electronic components needed, it was bulky, sensitive to changes in temperature and to noise or vibration.

In spite of those disadvantages, the ACE Pilot was considered for some time to be the most powerful computer in the world. The London *Times* noted on Nov. 30, 1950:

"The speed at which this new engine works . . . could perhaps be grasped from the fact that it could provide the correct answer in one minute to a problem that would occupy a mathematician for a month.

"In a quarter of an hour it can produce a calculation that by hand (if it were possible) would fill half a million sheets of foolscap paper."

ACE was used for five years and eventually placed on exhibit in the London Science Museum.

In 1949 Turing had accepted a position of assistant director of the Manchester Automatic Digital Machine (Madm), said to have been the first stored-program computer ever built.

The wife of Turing's close friend, Professor of Pure Mathematics at

Victoria University in Manchester, Maxwell H.A. Newman, said of that epoch: "I remember sitting in our garden at Bowdon, about 1949, while Alan and my husband discussed the machine [Madm] and its futuristic activities.

"I couldn't take part in the discussion and it was one of many that had passed over my head, but suddenly my ear picked up a remark which sent a shiver down my back. Alan said reflectively, 'I suppose when it gets to that stage we shan't know how it does it.' "

Turing's theories on the relationship of the computer to the brain influenced countless scientists studying "cybernetics," the term coined by MIT professor Norbert Wiener [Part 4] to mean "control and communication in the animal and the machine."

In 1951 and 1952, Turing took part in a series of radio debates on computers and their ability to think. One amusing retaliation to his theories came from Prof. Geoffrey Jefferson, who commented, "It would be fun someday, Turing, to listen to a discussion, say on the Fourth Programme, between two machines on why human beings think what they think."

"Why human beings think what they think," indeed. At the peak of his career and in the prime of life, Alan Turing was found dead in bed, on June 8, 1954, at the age of 42. His death was caused by poisoning from potassium cyanide, ruled at the inquest to have been self-administered.

Sara Turing, who later wrote a book about her son's life, did not accept the verdict of suicide, as many of his friends also refused to do. For whatever reason he died, Turing's life will not soon be forgotten.

His mother established the Alan Turing Prize for Science to be awarded annually at the Sherborne School, where a new science building was named the Alan Turing Laboratories.

In addition, since 1966, the Association for Computing Machinery (ACM) has annually given its highest award, The Turing Award, for technical contributions to the computing community.

Alan Mathison Turing's name and influence live on.

# Part 9 . . .

# KONRAD ZUSE

## *An Interview With the Inventor Of the World's First Fully Functional Programmable Digital Computer*

**By Brad Schultz, Senior Editor,** *Computerworld*
**And Elmar Elmauer, Senior Editor,** *Computerwoche*

*This interview was conducted Oct. 2, 1980 at the home of Konrad Zuse in Hunfeld, West Germany, about an hour's drive from Frankfurt. Its publication marks the 40th anniversary of the completion of Zuse's Z-3 computer.*

**Schultz: Are you the first person to invent an electronic digital computer?**

**Zuse:** I did not begin with electronic computers, but with mechanical and electromechanical computers. I was a student at the Technical University in Berlin, and I was studying civil engineering.

Civil engineers have to make great quantities of calculations, tables and so on. I was not delighted by that and thought it should be possible to make this automatically.

But I looked at computers that were available at that time, but no computer, even [those with] punchcards, was suited for this purpose. So I decided to go perfectly new ways.

I did not understand anything of calculating machines, so I was free to go new ways and to choose the best system for calculations, the binary system; to choose the principle of programming; and to choose what you call today "floating point" [arithmetic]. And so I began in the home of my parents, with some homemade devices, in a perfectly private place.

**Schultz: When was that?**

**Zuse:** It was in the beginning of 1936.

**Schultz: Were you influenced by other researchers?**

**Zuse:** No. For instance, when I was beginning, around 1934 or 1935, when I had the first ideas, I did not know anything about [Charles] Babbage [Part 3]. I only knew that there were existing punchcard machines, but I did not know the details of them. I only knew they could not help me.

And so I began from the beginning without any influence. Surely, I knew that the binary system was known to mathematicians, but I did not know that colleagues of mine had already worked on machines in binary.

**Schultz: Why did you select binary digital technology as opposed to an analog system?**

**Zuse:** I had the impression that information cannot be transferred or represented by a programmable computer in a way man is accustomed to . . . I decided to take the binary system because I had the impression that the electromagnetic relay is very well suited for computers [as a way to express] a binary digit.

**Elmauer: You say you hadn't heard anything about another researcher. Was the time between 1930 and 1940 ripe for development of an automatic calculating machine? You may have been pursuing your own interests, but Alan Turing published his ideas in 1936 [Part 8].**

**Zuse:** Turing came from the other side. He was a mathematician, a logician. He [wanted to explore] mathematical systems with the motor of a computer. At first, he did not have it in mind to make a computer for science. But he took the computer as a tool for his mathematical [interests]. . . . I came from the other side. I [wanted] to make a computer for engineers. And I saw mathematical logic, especially the calculus of propositions, as well suited to helping an engineer make a good machine.

I came from the other side and so logic and computing were combined. [Turing] made the combination from his point of view. I made the combination from my point of view.

**Schultz: So originally, the computer was meant to be a tool for engineers?**

**Zuse:** At first.

**Schultz: And you didn't see it going into the world of business?**

**Zuse:** When I had made the first steps in developing the computer for scientists and engineers, I came to the point where I saw that the term "calculating" is much broader than only calculating with numbers and that logical operations are essential. But at the time, it was difficult to discuss these problems. I saw no limit [to what computers can do] and surely [believed] that development [of applications] one day should go broader, outside purely scientific calculations. But at first, I had in mind to develop a theory of general calculating, universal calculating.

For instance, I took the chess problem because I had the impression that on the chess field, in rather a small place, you have very complicated connections from the logical point of view. My purpose was not to make a machine to one day fight the world champion. I only took the chess problem as a way of testing my [programming] language, [as a way of] formulating [the rules] of universal computing. I thought: When I am able to formulate the problems of chess with my language in my computers, then I will have such universal principles that I can go into other fields [of application] with no difficulty.

**Schultz: So you saw the computer as a tool in making decisions. Did you conclude that a person must have various kinds of information with which to decide something, just as a chess player has various kinds of information to consider — such as what his opponent may do in reaction to different moves?**

CW Photo by A. Dooley

**Konrad Zuse**

**Zuse:** Well, the term "decision" . . . Normally, we speak of a decision as [having] some relevance for us. [For example,] I decide if I will study or not . . .

But for a computer, the decision is not more than the calculating of a bit. And this happens millions and billions of times each second of every year in a great computer. I came to the point that I saw calculating begins, or computing begins, with the bit.

The bit is the lowest level of computation. Systematically, you can arrange higher levels of calculation. There was no reason to take the term "decision," to give it a special relevance. Already, on the lowest base, you have decisions, decisions, decisions.

**Elmauer: So you see the computer purely as a number cruncher?**

**Zuse:** I use the binary system not only for numbers, but to [organize] the mathematical point of view.

**Schultz: Why did you decide to study engineering? How did you develop ambitions as an inventor?**

**Zuse:** When I was a young man, 18 years old and full of ideas — fantastic ideas, not [always] the best — I began to study architecture. At times, I thought of becoming a designer. Then I studied civil engineering and saw that I had to prepare myself with all these difficult calculations. I had no choice. But I very much wanted to be an engineer because, from the early days of my youth, I liked technical problems.

**Schultz: You were 18 in 1928. At that time, you went to the Technische Hochschule at the University of Berlin, and you were studying civil engineering. You saw a need for a machine that could help engineers solve a lot of their problems rapidly, and that's how you got the idea for a digital computer. How did you first begin to build this thing? How were you able to get the**

**circuitry and mechanical parts that you needed?**

**Zuse:** My first ideas were to make a machine with electromagnetic relays. Then I realized that I would need thousands of relays and that this would take a whole room of boards of relays. I did not have the money to buy the relays.

In contrast [to such a machine], at that time, a calculating machine was something you'd put on a table. I did not believe anyone would be prepared to buy such a great thing [as an electromagnetic digital computer]. That was a psychological factor.

But I developed ideas for concentrating the electrical circuits necessary for a computer, and I succeeded in making [data] storage in a mechanical way. For that time — 1935, 1936 — that was very much to have accomplished.

. . . I believed I could make the calculating unit from the same technology, with pure mechanical switching agents, relays. But it came out that it was rather difficult; the computer is too complicated and you need too [many] connections from here to there, from there to there, and you can't make it always by mechanical means.

And so I came to the conclusion that I must go at least for the calculating unit — I must take electromagnetic relays — and that was about 1938. By 1939, I had a relay computer ready that was a model [called the] "Z-2." That was only a test model.

**Schultz: When did you build the Z-1?**

**Zuse:** The Z-1 was purely mechanical. [It was built in] 1936-38.

**Elmauer: How big was it?**

**Zuse:** It was about two meters by two meters.

**Schultz: You built this in the living room of your parents' home?**

**Zuse:** Yes . . . All this was in Berlin, where I was until the war ended in 1945.

**Schultz: How did the Z-2 differ from the Z-1?**

**Zuse:** The machines Z-2, Z-3, Z-4 [and subsequent Z series models] all had electromechanical relays. [Besides,] my friend Helmut Schreyer, the Austrian, in 1936-37 already had the idea to make [a computer] with [vacuum] tubes. Schreyer was working in parallel with the Austrians toward development of an electronic machine . . . He was just here some weeks ago for a visit. He now lives in Rio de Janeiro and Brasilia.

**Schultz: So Schreyer developed the circuitry that you specified?**

**Zuse:** I had already developed the [theory of operation and basic components for a digital computer], so I only needed [a means of] connecting these . . . units. When Schreyer saw [my plans for a] machine, he told me to develop it with tubes. This was around 1937. At first, I thought [his suggestion] was foolish. But then, after thinking it over, I concluded that [I needed] electronic circuitry with tubes for the basic operations of the calculus of propositions. And I saw a way to combine [this circuitry].

**Schultz: So you have the three basic logical operators: AND, OR and NOT?**

**Zuse:** Schreyer had them [implemented] in smaller test circuits. Only he was able to do that. But he could not give full attention to this [line of research]. Even during the war, we had very little assistance, officially, in our development [of computers]. Schreyer's main job was teaching at the Technische Hochschule in Berlin. He was only able to develop electronic computers [as a sideline].

**Schultz: How did you support yourself while working on computers?**

**Zuse:** Until the beginning of the war, I had no job. I made my own private [research facility]. In 1939, I was conscripted as a soldier — I was perfectly alone and dreaming and didn't see what was happening around me. They took me in, but after a half-year, I was made an engineer [assigned to] aircraft manufacturing.

**Schultz: They discharged you from the German army?**

**Zuse:** They needed engineers. [They chose me not for work on computers, but] as an engineer in aircraft [manufacturing]. I was operating this way until the war ended.

**Schultz: As an engineer, did you still have some rank in the army?**

**Zuse:** I left the army. I became a civilian again.

**Elmauer: You spoke about your friend, Schreyer. How long were you a lone researcher in computing? You started in 1936 to 1938. When did you find your first [colleagues]?**

**Zuse:** Until 1945, I worked alone in parallel with Schreyer.

**Elmauer: You began in 1936?**

**Zuse:** Yes.

**Elmauer: When did people first approach you with ideas about computing?**

**Zuse:** I had some friends who helped me, students mostly. I knew them from studying . . . others were well-known. And they helped me on a private basis. The sum was very small, very little amounts of money. Some helped me in the workshop, soldering the relays and so on. And during the war, I could make a small workshop and, by the end of the war, I had about 20 people with me.

**Elmauer: Do you remember when the German government first recognized the importance of calculating machines?**

**Zuse:** I doubt that the government realized the importance, not the government directly. Indirectly — that's another question.

The first contact I had [with the government] was with the [German Aircraft Research Institute] in Berlin . . . This was the largest research institute in Germany. At the time, they had a problem. The pure aesthetic of the aircraft was well-known and going well, but there were dynamical problems. The wings were flutterble for us and we decided not to go there. But we had [direct] contact with Werner Von Braun only at that time, in the last weeks of the war.

[Von Braun had] a small staff of about 60 or 80 people [that were fleeing] south . . . We [managed] to get a truck [and] put our machine on it and follow [Von Braun's group], only in the last days of the war. I had contact with Werner Von Braun, and we could spend the last days of the war in a very nice place.

[Zuse later told Schultz that he, Von Braun and other fleeing inventors were trying to avoid capture by the Russians. They very much preferred capture by the Americans or British.]

**Schultz: So your association with Werner Von Braun was of the nature of two inventors who realized the war was over and who just wanted to get together and figure out what to do next?**

**Elmauer: He met Werner Von Braun by chance.**

**Zuse:** No. General Dornberger arranged to help us . . . I think Dornberger [decided that the Z-4 should be rescued] — that it should be brought inside the house [where Von Braun was seeking refuge at the time].

[Lt. Gen. Walter Robert Dornberger oversaw Von Braun's development of the V-1 and V-2 pilotless rocket bombs at Peenemunde. These "weapons of reprisal" [*Vergeltungswaffen*], as Nazi propaganda minister Paul Joseph Goebbels dubbed them, killed thousands of British civilians.

[Von Braun later set up a small computer development group in the U.S. as he directed U.S. production of missiles and contributed to the astronaut projects. Consultant Forest Woody Horton, who worked with Von Braun's computer group 30 years ago, told *Computerworld* he did not recall mention of Zuse during that period. American computer technology — unlike American missile technology — therefore does not seem based on research sponsored by the Third Reich.]

**Elmauer: How did your Z-4 computer compare with other computers developed in America and England in the 1940s?**

**Zuse:** When we first heard of [Howard Aiken's Mark I at Harvard University, announced in 1944], we were astonished! What do they do with so [many vacuum] tubes? We had made a proposal for a computer with 2,000 tubes for the German aircraft industry, but at the time they couldn't help us. We couldn't get the assistance, people, material and so on.

They asked when the machines [would] work. We said about two years. They said we would win the war by that time. We are convinced that with the circuits Schreyer developed, it would have been possible . . . to come to the same result [as Aiken with much fewer vacuum tubes].

. . . Just some weeks ago, I was with Schreyer in London at the National Physical Laboratory and we had the opportunity to have a meeting with this Colossus [the machine England developed during the war to crack cryptographic codes]. And even in some things, circuits of Schreyer were better than the English. We know today that the circuits the English used for Colossus would have made a computer. They would not have needed so many tubes [as Aiken]. They had better circuits.

**Elmauer: You had to do most things by hand when you started building computers.**

**Zuse:** Yes, it was very convenient for me in 1937-38, when I made my first computers in relay, that the relay was already constructed. I only had to take the relays and solder them to make the right connections. Surely that helped me very much. Schreyer, for his electronic computer, was not in this position. He at first had to develop the [circuits] and then go over to the real computer.

**Elmauer: Can one develop such ideas without influence from the society in which one lives?**

**Zuse:** Well, . . . in the first years of my development, I was working like a monk, and I had only very little contact with the outside. I had some friends, but only very few understood what I [was doing]. So, for the first years, I developed without any [social contacts] at all.

**Elmauer: You once wrote about the dominance of mathematicians over**

C.W. Photo by A. Dooley

**practical men and how that affects development of computers. What did you mean?**

**Zuse:** There is not always good cooperation between theoreticians, mathematicians and crackpots . . . It is not good [when] the computer is only a mathematical [fantasy]. There exists another [practical world].

**Schultz: As war is too important to be left to the generals?**

**Zuse:** I saw it is not good to leave development of the computer only to mathematicians.

**Elmauer: Why?**

**Zuse:** The mathematicians make the world seem much too theoretical. For instance, in 1945, when I was in a small village after the end of the war in the Alps, I had nothing to do — surely the only thing was to survive. [It was then] that I had time to make my theoretical developments. By that I mean the first programming language for computers. This was especially organized for practice. And 10 years later, we had a big series of languages — very complicated. Even today, they are very complicated.

**Schultz: Was Plankalkul what you would call a high-level language?**

**Zuse:** Yes, I think it's the only universal language you have. There is no other. It's a universal language for calculating.

**Schultz: Is Plankalkul used today?**

**Zuse:** No, it is not used.

**Schultz: What do you think of the languages used today, such as PL/I, Algol, APL, Cobol and Fortran?**

**Zuse**: I think in some ways they are too complicated. My opinion is that data processing begins with the bit; and from the beginning, I decided to begin with the bit and to make all more complicated structures with data structures . . . When in 1945 I was sitting in a small village, [my computer] was hidden and [I] couldn't work at this. You didn't need a programming language for the Z-4. So I was not bound to existing computers.

Ten years later, when these languages like Algol and Fortran were developed, they were developed for machines then existing. These machines had many restrictions, so the languages to program them had restrictions, too. Only step by step could the scope of languages be enlarged.

**Schultz: I have heard you had some anxieties, some fears, about what computer technology might do in society — that you considered it dangerous. Did you feel it was dangerous for a program to be affected by results of its own execution?**

**Zuse:** I saw that there was a danger; so long as this feedback is not built in a computer, the computer is harmless, not dangerous. You can see what it does.

From the moment when this line is made [a loop from program output to the program itself], there is no possibility for you to see where it goes. I doubt that when [John] Von Neumann made this line, he realized the whole scope of what he did.

**Schultz: I suppose that the danger you see in this line would be that when people become very dependent on computers, when they rely on computers to help them make very important decisions, they come to believe that computers are infallible. Then the results of a computer that does have that line seem valid to them, but in fact may not be valid, and therefore result in unfortunate decisions for the world.**

**Zuse:** One thing is the famous order GOTO. If you are perfectly free in this feedback and can jump from any point in a program to any other point . . . there are very complicated restrictions. You can jump with your brain in your head from here to there and [not lose track of your thoughts], but it is not so for the computer. I did not have this form of GOTO in Plankalkul. Structured programming was built into Plankalkul from the beginning so you couldn't make any nonsense.

**Schultz: So the GOTO statement is dangerous if you have this line leading between the central processor and the program being executed. Isn't that what you're saying? I wonder if you sympathize with the opinions of Edsger Dijkstra of The Netherlands, who for years had argued against the use of the GOTO statement?**

**Zuse:** I only know I have not studied the works and papers of Dijkstra in detail. . . . Modularity is built into Plankalkul from the beginning.

**Elmauer: What do you think of developments in hardware today?**

**Zuse:** I am not a specialist in hardware [anymore]. I think that we have made much progress in miniaturization, integration and so on. I am interested in the field of automata theory. I have worked in this field only on a theoretical basis.

[At present,] we don't have a good economical, working computer for associative memory. You would think now that we can concentrate storage capacity in a small place and make it with transistors and so on — active elements — and for the first time make an associative level with memory in combination with normal memory. But this point is not yet reached.

**Schultz: Could associative memory be developed through a combination of analog and digital technology? Is there a way of combining the two?**

**Zuse:** Associative memory means to have a memory where I have access to the contents of the memory, not to an address but to the contents itself. We know the human brain works on this principle. Quite another technology, it's clear, but it works from a logical point of view . . . The step [toward associative memory] has not been taken by the computer industry. Technology has not yet reached this point.

**Elmauer: What about the software crisis?**

**Zuse:** I am an old man and I am tired. For 10 years, I asked people [as a teacher] why do you make programming languages so complicated? But nobody heard of me . . .

You have the proverb in English: the shoemaker's children wear the best shoes. Computer people have developed the computer for the sciences, but they haven't developed the computer for themselves.

What we need is a very good instrument to make our own programs . . . The theoreticians at the universities, they make big theories of languages and theories of machines which are wonderful houses of cards.

**Schultz: When we were talking about what you were doing at the end of World War II, we last left you in the Alps. Where did you go after that? Were you in hiding for a while?**

**Zuse:** No. We had very difficult years in Germany until 1948. One could only see how to exist until the next morning. It was difficult to make any business. I had contact at that time with IBM, but they were only interested in my patent applications, not in my machines.

**Schultz: How did you contact IBM?**

**Zuse:** . . . In this village [Hinterstein, near the Austrian border], there came at the end of the war a lot of people. Nobody knew the other. There was only one street in the village. A week later, everybody knew everybody.

There was a German filmmaker coming from Berlin. He had an American wife, so he was able to leave Germany in 1946. He went to

America. I told him [in Hinterstein] about my machine, the Z-4. Then he contacted Watson of IBM and . . . Watson sent a telegram to the [West German branch office] of IBM, at that time — in Stuttgart — and [representatives of the office] visited me in the village.

[We negotiated.] But these [representatives] had no authority to decide anything. They were interested in my machine. I showed them it. We made a contract. I got some [money] from them which helped me. It was in Reichmarks.

. . . But then came the [terrible inflation]. My contract was just ending [every six months] and they had to keep doubling their payments to me [to adjust for the Reichmark inflation]. That was excellent for me. But they were only interested in patent applications. I said, "I have rescued this machine, the Z-4. I will work with it for . . ." They said, "No, you can't do that. Not with IBM. We are not interested in the computer. Only patents."

Under very hard conditions, I had saved the Z-4 from Berlin. It was very adventurous. We liked this machine. It was perhaps the only working computer in Europe at that time. I wanted to make a contract with anyone, maybe IBM, to continue work with my machine. IBM didn't like this.

Until 1948, I had the impression the big American [high technology manufacturers] did not see the whole scope of the development coming in electronics. They thought [electronics] was [to build] toys for mathematicians . . .

**Schultz: In 1948, you had a contract with Remington Rand?**

**Zuse:** . . . and with a competitor, Hollerith and Powers. In 1949, I formed a company with two partners, Zuse KG. . . . We delivered about 40 machines to Switzerland . . . The Z-9 computer was a combination of a relay computer made here in Germany and a punched card device which was made in Switzerland. The machines were marketed by Remington in Switzerland.

**Elmauer: How big was your staff when you founded your first company?**

**Zuse:** Well, we began with four people and then we enlarged this year by year. When I left the company in 1966, we had a thousand people. [Zuse described how he was persuaded to step down from a "steering" role in the company by his partners, who were more business-oriented.]

**Schultz: In the last few years, some people have speculated that the time has come for software to be burned into the circuits so that you would have an operating system that would be stamped out on a chip. Do you think that is feasible? Do you think that a lot of the software that someone might buy will eventually be hardware in a sense, it will come on a chip?**

**Zuse:** I think that we shouldn't — and in some way we are returning to forty years ago when I was beginning. Take my computer, Z-4; there was a logic wired in, a very complicated logic — two floating point and a . . . — and we had a great difficulty with it. We had reached a high level of wired circuitry logic. And then came the electronic computers, and the electronic computers were the first step, better made the same thing, and then a rather simple central processor, not so complicated as ours.

And this development is today not yet finished, but now we have a new situation — now we are able again to concentrate logic, to make wired logic. And to concentrate it on a small field and so we can make the same thing [that] forty years [ago] we did with relays. Now you can make with this other stuff, and I think this is the right way.

**Schultz: Do you suppose this might affect the need that organizations have for programmers? Do you think there will come a time when there will be much less need for an organization to have a large staff of programmers?**

**Zuse:** I will say it this way. I think there is only one step to solve the software program. You can't make . . . anyway you will need programming in the combinations of these things. You can't solve all this with logic. You can do, too, but there are some reasonable limits, yes, nobody knows where.

**Schultz: What about firmware? Firmware is the expression in the U.S. for microcode, for programs, and typically this is stored in erasable programmable read-only memories. They have become popular, as you know very well, in the last few years to tailor a computer to a specific sort of environment, to make it especially suitable for certain applications . . . dedicated systems. At any rate, do you think that in the future a lot more of the programming will be done at this level, at the level of firmware, rather than what has been the case up to now, writing applications that are stored on disk that have to be coordinated in a very complicated way by an operating system?**

**Zuse:** Well, the term "firmware," I am not very well familiar with this limit between firmware and operating system, how far goes the general operating system which is delivered with the machine by the manufacturer and when begins the firmware. And surely it would be very convenient if you can deliver these machines with a universal set of operating systems and special limit, specialized for special calculations in firmware, but the friction between operating system and firmware must be elaborated very carefully.

**Schultz: Another trend that seems to be developing is where a computer system is actually a number of processors tied together, and each processor is devoted to certain functions. It might, in fact, be comprised of little microprocessors that are individually microprogrammed for certain tasks so that everything is very modular and very hierarchical, and this seems to be a way of making your computer resources most efficient. Do you think this is the right approach to take?**

**Zuse:** Well, I'm not so familiar with this field.

**Elmauer: What about centralization vs. decentralization?**

**Zuse:** Well, I think in general you should only make centralization where it is necessary from a logical point of view.

Take all these difficulties you have now with privacy. The transparency of the systems gets difficult if you make too much centralization. Perhaps 10 or 15 years ago all people thought that the solution was to have one big central computer and all two hundred or a thousand users connected with it. I think now we can, and we have, the possibility to make not very expensive processors for everyone, and so you should only centralize if you need the centralization from a logical point of view.

**Schultz: What about these very small computers, these personal computers, that are affordable by a lot of people now because they're relatively inexpensive. Do you suppose that the proliferation of these personal computers will make it easier for someone, some child, let's say, similar to the way you were when you were young, who has ideas for inventions and things, to educate himself?**

**Zuse:** I have my opinion. I myself don't need any microcomputer. I take my brain, and my paper and so on. I can imagine that these microcomputers can help . . . , for instance, a lawyer, an attorney who has much letters going in — if you can take a computer and he only gives some dates and he knows where this letter is and so on, an automatic secretary, yes? These personal computers, I don't know. Perhaps one day when you tell the people enough, "you need it, you need it, you need it," perhaps one day they will need it.

**Elmauer: Do you think that our society is educated enough to use a computer correctly and knows enough about what a computer can do and what a computer cannot do?**

**Zuse:** First, I think our society is not yet at the point to exploit the computer in the right way.

We have very great difficulties everywhere, and you know all the difficulties. Nobody is able to solve the problem of unemployment, or inflation and so on, nobody.

Take us in the capitalistic countries. The socialistic countries are only running because they have two parallel economies — one is official and the other the black market, only these two together give a working system. And so no government is able to solve as a problem that which has confounded us.

And surely it is not so that when you use a computer in the right way, our problems are solved; but, on the other side, I think without computers it is not possible. You need much better use of the computer to solve the problems better than now. And you must go much more in detail with all your programming and all your information you get from the development of the economy of the country and so on to make decisions very quick.

And so I think today, we are only in the beginning of societies which are based on the computer. We must solve this problem during the next generation.

**Schultz: It's perhaps ironic that the technology that is used to try to organize and to improve society also changes the nature of society. There is a feedback. Do you see it that way?**

**Zuse:** In the long line, on the whole earth today, we are experimenting on every part, the U.S., Peking, Japan, Berlin — they all are experimenting how to solve the problems. Nobody until now has a real good solution. And also the priests of socialism see that with illusions you can't solve the problem. Just now, we have a change in the minds of all peoples of the world. The revolutionists see with revolution nothing to make. The socialistic states see that the organizations they had until now are much too stiff, and they must go much more in detail. We must solve the problem.

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# *It Began in Berlin . . . In his Parents' Living Room*

**By Brad Schultz**
CW New York Bureau

*The programmable digital computer was invented by Konrad Zuse in Berlin during Germany's Third Reich.*

*Born in 1910, the son of a postal administrator, Zuse began developing computers in his parents' living room after he graduated from Berlin's Technische Hochschule with a civil engineering degree in 1935. Until World War II erupted, Zuse generally subsidized his own research, working as a stress analyst for the Henschel Aircraft Co.*

*By 1938, Zuse (pronounced TSOO-zuh) had developed a symbolic notation for binary arithmetic that translated to the electromagnetic relays from which he would build a series of computers, initially termed Versuchsmodell (Experimental Model). The first Versuchsmodell, the V-1, was built in that year; it was totally mechanical and never left the home of Zuse's parents.*

*Zuse viewed the Versuchsmodell series as tools for engineers and scientists. As a stress analyst concerned with the thorny aerodynamic equations used to design aircraft, Zuse believed that digital computers were desperately needed by researchers and developers because the applied mathematics required to advance technology had grown too cumbersome.*

*Zuse was drafted into the army after the war began in 1939, but many engineers like him were soon released from military service and assigned to engineering projects that supported the German war effort. Zuse was assigned to the German Aircraft Research Institute in Berlin.*

*Back in his native city, Zuse continued to develop the Versuchsmodell series at his parents' home, and largely out of his own pocket, while working at the institute, which designed military aircraft for the Luftwaffe. Helmut Schreyer, who studied telecommunications engineering at the Technische Hochschule when Zuse was there, helped Zuse find used electromagnetic relays for the second Versuchsmodell, the V-2.*

*Schreyer showed Zuse how these relays could fit Zuse's overall plan for digital computers. Schreyer, who now lives in Brazil, also advised Zuse on implementation of vacuum tubes, which served as digital switches, and eventually produced a version of the "flip flop" circuit, now ubiquitous in computer logic.*

*The V-2 was never reliable, but one of* *the few times it ever worked right was when Alfred Teichmann, a top scientist at the German Aircraft Research Institute, visited the Zuse home at Zuse's invitation. Teichmann was an authority on a vexing problem in aircraft design: wing fluttering. He was immediately convinced that machines like the V-2 could help engineers eliminate fluttering by solving aerodynamic equations. The flutter problems had "burned under the fingernails," Zuse later recalled.*

*Teichmann helped Zuse get money for further development of computers, but Zuse continued to work in his parents' home and never was given a formal staff of assistants. With Schreyer's aid, Zuse completed the world's first fully functional, program-controlled digital computer late in 1941.*

*This third Versuchsmodell was initally called the V-3. It had 1,400 electromagnetic relays in memory, 600 relays to control arithmetic and another 600 relays for other purposes. Featuring a binary floating-point number scheme, the V-3's word length was 22 bits. The capacity of V-3's random-access memory was 64 words.*

*The V-3 handled a multiplication operation in three to five seconds. The problem most frequently handled by it was evaluating the determinant of a matrix (which is a method of solving equations with several unknown variables). The V-3 apparently was the first machine to employ "Reverse Polish" notation, a means of expressing mathematical propositions whereby numbers precede mathematical operators.*

*A Polish logician, Jan Lukasiewicz, is credited with inventing this notation in the 1920s, but Zuse did not know of Lukasiewicz's contribution; he simply "reinvented the wheel," just as other scientists in the U.S. and Britain would cover the same ground as Zuse without having heard of him.*

*During World War II, Zuse redesignated his first three computers as the Z-1, Z-2 and Z-3, respectively, to avoid confusion with the V-1 and V-2 rocket bombs being developed by Werner Von Braun for launching against Britain. Zuse always intended his Z series computers to be general-purpose, but he developed at least one special-purpose computer — a variant of the Z-3 — which seems to have directly supported the German war effort.*

*This special-purpose computer, the S-1, helped the Henschel Aircraft Company manufacture a flying bomb known as the HS-293, according to at least two writers. (Zuse denied this connection with the HS-293 in the interview he gave* Computerworld *and* Computerwoche *a year ago.) Never so well-known or widely used as Von Braun's rocket bombs (which Nazi propaganda minister Paul Joseph Goebbels called Vergeltungswaffen, "weapons of reprisal"), the HS-293 was an unmanned airplane, carried aloft by a bomber.*

*The bomber pilot would line up a target in his sights, release the HS-293 and have the bomber crew guide the plane by radio to the target. The HS-293 reportedly blew up Allied ships after August 1943 and also destroyed bridges in Poland as the Germans retreated in 1945.*

*The S-1 computer worked reliably from 1942 to 1944 at the Henschel plant in Berlin, measuring inaccuracies in wings and rudders turned out cheaply for the HS-293. Workers would measure the true dimensions of the wings and rudders; these measurements were fed into the S-1, which then calculated how the HS-293 would deviate from a straight path if those parts were assembled normally.*

*Zuse developed a method of programming his computers that did not require the programmer to understand details of a computer's internal organization. He dealt with what may be called the world's first programmer shortage, as the war sapped manpower, by asking an institution for the blind to send a list of blind people who showed talent for mathematics.*

*From the list Zuse hired one August Fast, who then became so proficient in programming that Zuse tried, unsuccessfully, to raise funds for a Braille translation of* Ansatze einer Theorie des allgemeinen Rechnens, *Zuse's major theoretical treatise. He reasoned that Braille copies of the* Ansatze *would lead to a base of blind programmers who could further computer technology without risking conscription into the military.*

*Zuse was working on the Z-4 computer when he learned that Howard Aiken of Harvard University had produced what seemed to be America's first programmable digital computer, the Mark I [CW, Sept. 21]. Actually, John V. Atanasoff at Iowa State College (now University) had most elements of what was really the first American computer running in 1941, around the time Zuse was completing the Z-3.*

*Atanasoff's machine, intended to help students solve mathematical problems, was not "fully functional" like the Z-3; it only handled certain kinds of calculations. The Mark I, announced in 1944, was the first programmable computer Zuse knew of as not originating, at least not conceptually, in his parents' living room.*

*(Zuse's friend, Schreyer, had tried his own hand at producing computers. Schreyer asked the German High Command early in 1942 to subsidize a computer development project that would take two to three years. He was turned down on the grounds that Germany would win the war in that time, eliminating the need for such a tool.)*

*The British tried cracking German secret codes with an all-electronic deciphering machine called Colossus [CW, Oct. 5], which began successful operation in December 1943 (some two years after Zuse completed the Z-3). A second, improved version, called Colossus Mark II, began working a few days before the Allied invasion of Normandy.*

*Colossus Mark II lacked internal storage for programs, but Zuse said it could easily have been adapted for service as a programmable digital computer, albeit less efficient than his own machine.*

*In the* Computerworld/Computerwoche *interview, Zuse said his initial reaction to news of Aiken's Mark I was astonishment that so many vacuum tubes could be assembled for such a purpose. Zuse completed the Z-4 by the end of the war in 1945, despite Allied bombing raids that damaged his workshop several times, forcing him to move the Z-4 around Berlin on three occasions and completely destroying the Z-3 on April 6, 1945.*

*According to the interview, Zuse evacuated Berlin in March 1945. He dismantled and rebuilt the Z-4 several times in the years that followed; the fourth-generation Zuse computer reportedly was used until 1959.*

*The Z-4's mechanical memory had 16 words in 1947, 64 words in 1949 and 1,024 words in the 1950s. Its word length was 32 bits. The computer could multiply in one second and find a square root in five seconds; memory access was half a second.*

*Zuse developed a prototypal programming language called Plankalkul in 1945, which — in the context of Zuse's theoretical research in software — suggests that he anticipated and resolved a number of important issues that pass today under the rubrics of structured programming, theory of algorithms, programming methodology and the structure of programming languages.*

*Zuse's escape from Berlin brought him first to Gottingen, a city about 100 miles west of Berlin that was famous for scientific contributions, and then to the Alps. As he moved, the dismantled Z-4 was carried by wagon.*

*During the escape from beseiged Berlin, Zuse met Werner Von Braun, who had developed rocket bombs in the Baltic sea-*

coast town of Peenemunde and would, a few months later, begin developing missiles for the U.S.

In the interview, Zuse said that Lt. Gen. Walter Robert Dornberger, Von Braun's boss at Peenemunde, arranged evacuation of equipment and papers for both Von Braun and Zuse, among other people who had worked on sensitive technical projects. Dornberger apparently did not know Zuse prior to the chaos of that spring; there is no evidence that Zuse's development of computers was well-known to the highest officials of the Third Reich, such as armaments production minister Albert Speer, whose memoirs mention Dornberger and Von Braun but not Zuse.

Von Braun set up a small computer development group in the U.S. to support production of missiles and spacecraft. Consultant Forest Woody Horton, who worked with Von Braun's computer group 30 years ago, told Computerworld he did not recall mention of Zuse during that period. Therefore, American computer technology — unlike American missile technology — does not seem based on research sponsored by the Third Reich.

Zuse was called an "ardent Nazi" by Rex Malik in And Tomorrow . . . The World (Millington Ltd., London, 1975). Malik wrote: "The first computer to be put to practical use . . . was the product of a then ardent Nazi, ardent to the point that he was a believer in the possibility of the final stand, who went into hiding in 1945 and did not surface to be interrogated till 1948. His name was Konrad Zuse."

Computerworld asked Zuse to respond to this charge. Without declaring whether he believed in the principles of Nazism, Zuse replied that after the Battle of Stalingrad, he and most of his colleagues were certain the war was lost. (The battle ended in bitter defeat for Germany — the loss of an entire army — in February 1943.)

Zuse indicated that, because he believed the war was lost, he considered his work in computers to have value for society after the war, not just Germany.

Zuse took refuge in the Alpine village of Hinterstein, near the Austrian border, until 1949. Shortly after the war ended, he set about launching his own computer manufacturing company, Zuse KG. In 1948, Prof. E. Stiefel of the Federal Technical Institute in Zurich became Zuse's first customer, ordering a Z-4 for his laboratory.

Another early customer was Leitz Optical Works, which bought Zuse's next computer, the Z-5. The last of Zuse's electromagnetic relay computers, the Z-11, was built in the 1950s and reportedly is still used in a few places.

Zuse tried unsuccessfully to interest IBM and Remington Rand in backing his computer manufacturing plans. A German friend of Zuse's reportedly told IBM's Tom Watson about the Z series computers, but after some negotiations, IBM dropped interest, Zuse recalled.

Zuse was searching for a company or institute to sponsor his further development of computer technology. But IBM only wanted to buy Zuse's patents on existing technology, thereby acquiring royalties on fundamental components that were the foundation of many later machines.

As for Remington Rand, Zuse said that the company initially decided electronics was too risky a basis for digital computers, but expressed interest in a totally mechanical machine. Zuse eventually developed Z series computers that Remington Rand helped market in Switzerland.

Zuse's company was eventually acquired by Siemens AG, which retains Zuse as a semiretired consultant. The tall, engaging 71-year-old computer pioneer lives in the Hessian village of Hunfeld. He can easily walk from his house to a high school named in his honor, the Konrad-Zuse Schule.

In reflecting on how computer technology has developed since the 1950s, Zuse observed that programming languages have become far too complicated and bound to the idiosyncrasies of machines rather than people.

He warned against the dominance of theoreticians over practical people in development of computers and said the computer becomes socially dangerous when programs are affected by results of their own execution.

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The most exhaustive U.S. account of Zuse's contributions is the 1980 doctoral dissertation of historian Paul E. Ceruzzi, entitled "The Prehistory of the Digital Computer, 1935-1945: A Cross-Cultural Study" (Texas Tech University, Lubbock, Texas). Ceruzzi's dissertation was a primary reference for this article and his help in arranging the interview with Zuse is gratefully acknowledged.

# Part 10 . . .
# ECKERT & MAUCHLY: Pulling It All Together

It was a team like Rodgers & Hammerstein or Gilbert & Sullivan — a perfect blend of complementary talents that time after time produced compelling works to eventually enchant millions.

Together, Eckert and Mauchly produced four classics: Eniac, Edvac, Binac and Univac I, and without question deeply influenced the development of the computer industry as we know it.

Both were already interested in the possibilities of automatic computation when World War II turned possibilities into urgent needs. In 1942, the Ballistic Research Laboratory of the U.S. Army Ordnance Department was assigned the job of recomputing firing and bombing tables for the springier ground of Africa and for proposed gun/projectile combinations, rockets, missiles and other strategic arms.

Manual computation of a single trajectory for a given set of conditions normally took military specialists several hours with a desk calculator. In a "crisis of calculating," as Eckert called it, hundreds of operators were needed around the clock to develop the needed ballistic tables.

Mauchly wrote a memorandum in 1942, based on discussions with Eckert, called "The Uses of High Speed Vacuum Tube Devices for Calculating," suggesting that his idea for a vacuum tube computer would fill the Army's bill.

Courtesy Sperry Univac

**Mauchly (left) and Eckert**

The memo was misplaced and lay buried for almost a year before being resurrected by then-Lt. Herman H. Goldstine, formerly an assistant professor of mathematics at the University of Michigan before he joined the Ballistics Laboratory at Aberdeen Proving Grounds, Md.

At Goldstine's urging, Mauchly unearthed the original shorthand notes for the memo, had it reconstructed and sent immediately to Washington, D.C., for approval.

At one of the subsequent Washington meetings on the subject were Goldstine, director of the laboratory Col. Leslie E. Simon and Prof. Oswald Veblen of Princton University's Institute of Advanced Study, among others.

"After listening for a short while to my presentation and teetering on the back legs of his chair, [Veblen] brought the chair down with a crash, arose and said, 'Simon, give Goldstine the money,'" Goldstine recounted in his 1972 book.

From that point, the project moved very quickly. A team of 50 people (at its largest) was organized and, a year after proposing the idea, Mauchly — who was teaching full-time — found himself consultant to a project that owed its existence to a $400,000 contract.

Eckert — the only full-time person on the project — served as project manager and chief engineer and Capt. Goldstine maintained the technical liaison with the Ballistic Research Laboratory.

Begun in April 1943 — on Eckert's 24th birthday — Eniac was finished more than 200,000 man-hours later, three years after it was started. An enormous, clumsy piece of equipment by today's standards, Eniac weighed 30 tons and covered 1,500 square feet of floor space.

It contained more than 18,000 vacuum tubes, 500,000 joints soldered to connect all the circuits, 70,000 resistors, 10,000 capacitors and 6,000 switches. Eniac used 150 kilowatts of electricity, about equal to 200 horsepower.

With only two of its 40 panels containing mechanical relays, Eniac proved to be the breakthrough in speed that automatic computation was striving for. Completed only two years after Howard Aiken's IBM/Harvard Mark I [CW, Sept. 21], Eniac performed calculations 1,000 times faster than that relay machine.

Featuring the all-important concept of subroutines — now at the heart of all modern computers — Eniac also broke new ground in being electronic and containing stored program features.

Installed at the Aberdeen Proving Ground in 1947, Eniac worked on problems of weather forecasting, wind tunnel design and the study of cosmic rays, in addition to ballistics tables. At 5,000 additions and 1,000 multiplications per second, Eniac in half a minute could solve a problem usually requiring 20 hours with a desk calculator.

Although built for the purposes of war, Eniac was not completed until 1946, a year after Japan surrendered. Nevertheless, it was used for the next 10 years and parts of it can now be seen in the Smithsonian Institution, as well as at the Fort Carson Museum in Fort Carson, Colo.

In spite of its many advances, Eniac featured a rather overwhelming drawback: It was partly controlled by a combination of switches and a telephone switchboard-type "patch cord" arrangement. To change a program, the operator had to disconnect wires and plug them into different locations, a task that usually took several hours.

While Eniac was a vast improvement over the speeds of the previously developed mechanical analyzers, it quickly became evident that its still cumbersome programming technique would negate the computer's inherent speed. Eckert and Mauchly started planning a machine that would store the program electronically in the same way it stored data.

The "stored-program" machine, to be called the Electronic Discrete Variable Automatic Computer (Edvac), would not be completed until 1951 and would not be completed by Eckert and Mauchly themselves.

While Eckert and Mauchly worked on the concept, they were joined in 1945 by the brilliant Hungarian-born mathematician John Von Neumann, who had already worked informally with the project team.

In June 1945, Von Neumann prepared an outline of data learned from Eckert and Mauchly called "First Draft of a Report on Edvac," in which he described stored-program computers. The document was published even though the material in it was classified information, according to Eckert.

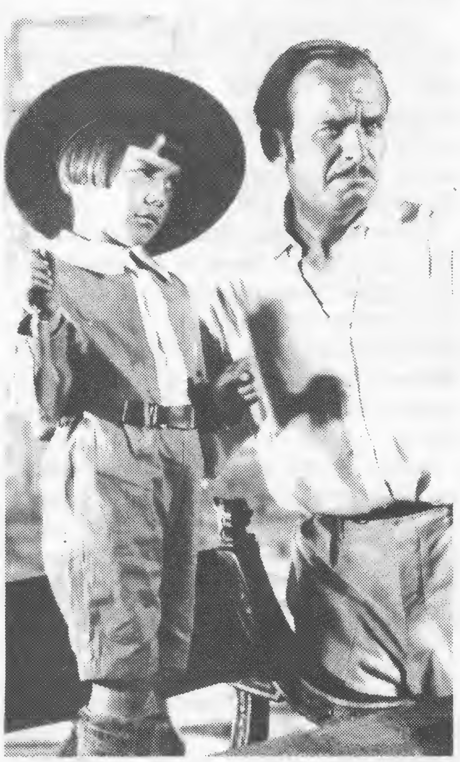
Because the draft carried only Von Neumann's name as author, he has generally been regarded as the originator of the stored-program concept, although Eckert claims it was he who originated the idea.

This point is one of several that are clouded by ill feelings and controversy in the history of computing. Eckert and Mauchly left the Moore School in June 1946 over patent disagreements — seriously impeding progress on Edvac — and in 1947 formed a partnership, known as Electronic Control Co., to design and build a Universal Automatic Computer (Univac). It later became Eckert-Mauchly Computer Corp., of which Mauchly was president and Eckert vice-president.

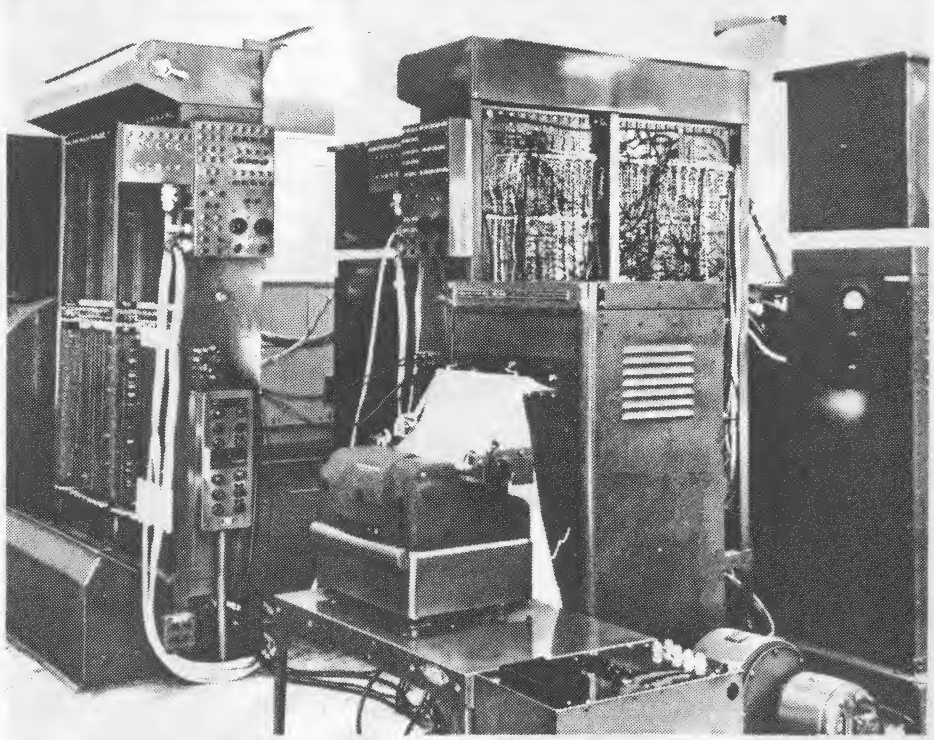
Even though they had formally left the Moore School in June, that summer they both gave several lectures there as part of a course entitled "The Theory and Techniques for Design of Electronic Digital Computers."

"That course did more for computing than anything," Eckert said recently. "We communicated more information then than anything else did. The students read like a Who's Who of Computing."

From information obtained during



**Eckert at Age Six With Actor Douglas Fairbanks Sr.**



Courtesy Sperry Univac

**Binac, Completed in 1949.**

the course, Prof. Maurice Wilkes of the UK's Cambridge University returned home to begin work on the Electronic Delay Storage Automatic Computer (Edsac), which he completed two years before the Edvac was finished.

Before the struggling Eckert-Mauchly Computer Corp. could finish Univac — because of delays by the Bureau of Standards on the Census Bureau contract — it took on another project to gain more capital. The Binary Automatic Computer (Binac), begun in 1947 for the Northrop Aircraft Co., was completed in 1949.

Binac, then, as the country's first operational stored-program electronic digital computer, was cheaper and faster than Eniac or Edvac and could handle magnetic tapes instead of punched cards.

Two separate Binacs were built; they could be used separately or together to check on each other. In Binac, Eckert and Mauchly incorporated the ideas they had first proposed for Edvac, resulting in a much smaller and more efficiently designed machine because of the total use of stored programs and an all-binary system instead of Eniac's partially binary system, Eckert explained. During the late 1940s, American Totalisator had agreed to finance Eckert and Mauchly's research and development work. In October 1949, however, their main support, American Totalisator vice-president Henry Straus, was killed in an airplane crash, leaving the pair in serious financial difficulty.

After exhausting every effort to get additional support, Eckert and Mauchly sold their company to Remington Rand Corp. in February 1950. Remington Rand merged with the Sperry Corp. in 1955 to form Sperry Rand.

In 1951, Eckert and Mauchly completed work on Univac I, the world's first commercially produced electronic digital computer. The Census Bureau, with the National Bureau of Standards as its agent, was the first organization to order a computer.

Dedicated in June 1951, Univac I was first used to complete the 1950 census. It was the first commercial computer to use a compiler to translate program language into machine language.

In 1952, a second Univac I became the first computer used to tabulate returns in a U.S. presidential election. In the race between Dwight D. Eisenhower and Adlai Stevenson, Univac I computed Eisenhower the victor only 45 minutes after the polls closed.

The Department of Commerce retired the original Univac I in 1963, after more than 73,500 hours of operation. Parts of the machine are now on display in the Smithsonian Institution.

After the completion of Univac I, both Eckert and Mauchly remained at Remington Rand, Eckert as engineer and Mauchly involved in the logic design and software for Univac.

Eckert went on to do development work on the Livermore Automatic Research Computer (Larc), the first machine to feature multiprogramming and multiprocessing, and helped develop Univac III.

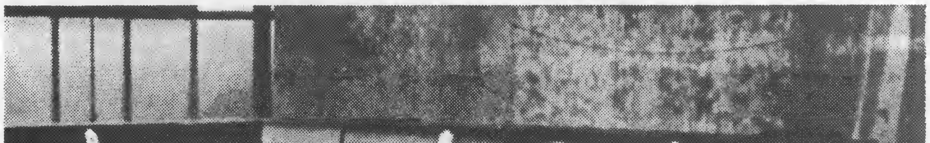
Eckert remains at Sperry Corp. to this day, as vice-president of the Sperry-Univac Division, although he does not do "that much inventing anymore." He does educate users about the firm's ongoing research and development, however, since "they're more likely to believe someone who's worked on computers all his life than a sales-type representative," Eckert observed.

Eckert lives in Gladwyne, Pa., with his wife, the former Judith Ann Rewalt, and two of their four children.

Mauchly worked for the Univac division of Sperry Rand as director of Univac applications research until 1959, when he formed Mauchly Associates, a group that developed computers for scheduling tasks and introduced the critical path method (CPM) for scheduling by computers.

Mauchly also formed a systems consulting company called Dynatrend in 1968. John Mauchly died Jan. 8, 1980, after a long illness. He is survived by his wife, the former Kathleen (Kay) McNulty, who was a programmer for Eniac, two sons and five daughters. In his eulogy of Mauchly, Eckert said, "John saw things really for what they were and not what people told him they were. And there's a big difference between those two things, when you come to try to invent something.

"It's the difference between being tied down by tradition and being guided by tradition into doing something new," Eckert said. Both Eckert and Mauchly can be seen as nothing less than visionary trailblazers who have contributed a monumental chapter in the history of computing.



Courtesy Sperry Univac

**Eckert and newsman Walter Cronkite examine Univac I, 1951.**

# *J. Presper Eckert Jr.: Success at an Early Age*

*"What puzzles me most is that there wasn't anything in the Eniac in the way of components that wasn't available 10 and possibly 15 years before . . . The Eniac could have been invented 10 or 15 years earlier and the real question is, why wasn't it done sooner?"*

— J. Presper Eckert Jr. (1962)

If Eniac, the first large-scale general-purpose, electronic digital computer, had been invented 15 years earlier, co-inventor Eckert would have been all of 11 years old. As it was, he was only 26 when the machine began to whir and hum.

Born April 9, 1919, the only child of prosperous Philadelphia parents, Eckert had a stimulating childhood peopled with such figures as Douglas Fairbanks Sr., Charlie Chaplin and President Warren Harding and punctuated with world travel totalling 125,000 miles by the age of 12.

The Hollywood stars were colleagues in John Presper Eckert Sr.'s World War I bond drive efforts and the travel included the elder Eckert's business and vacation trips.

Exceptional not only in the opportunities fate handed him, Eckert built a crystal radio set on a pencil at the age of eight and at 15 devised a remote-controlled bomb that exploded on his school stage from a push-button box in the audience.

The school was the William Penn Charter School, the oldest private boys' school in the U.S., where Eckert breezed through his regular courses and took on two years of college math as well. After graduating in 1937, he entered the University of Pennsylvania's Moore School of Electrical Engineering, where he stayed to teach, do research and pursue graduate studies after receiving his bachelor's degree in 1941.

Although obviously gifted, Eckert's early career at the Moore School was less than brilliant, because he had been unwillingly steered away from MIT by his parents.

Although anger at his parents showed in his first two years' grades, "I got over my anger and got top marks in my final exams," he said.

Undergraduate grades notwithstanding, Eckert's mind was never idle. During a summer recess in his undergaduate period, Eckert designed and built a device for measuring the concentration of napthalene vapor by means of ultraviolet light. During his last year of schooling, he perfected circuits for using strain gauges. He later worked to develop instruments for measuring the fatigue limits in metals.

When World War II broke out, he designed and built a device for recording rapid changes of very small magnetic fields. The device was used for testing methods for setting off enemy magnetic sea mines.

Other war-related projects included Eckert's work on solving several problems involving radar and on various timing devices for measuring radar targets to an accuracy of one yard out of 100,000 yards. It was here that he first applied digital concepts involving counters to electronic engineering problems.

It was in Eckert's role as lab instructor, at age 22, that he met the 34-year-old Mauchly, one of 20 "students" — 16 of whom had Ph.D.s — whom Eckert had to simply "aim in the right direction." The course was an eight-week government-paid defense course in electronics.

"I had little to do," Eckert recalled, "so John and I talked. Since he taught physics, there was no need to teach him. Instead we discussed what we really wanted to do — build a computer."

Two years after their initial meeting, when Eckert had received his master's degree in electrical engineering, the two joined forces to begin work on the Eniac.

In Mauchly, Eckert had found a mind that complemented his almost perfectly and did so for many years, until Mauchly's death in 1980.

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# *John William Mauchly: Humanistic Scientist*

*"History is certainly going to change its point of view about me and Eckert and lots of other people. We think it'll change with respect to who did what so as to reflect the part we really played in the invention of the computer."*

— John W. Mauchly (1979)

Mauchly's words — spoken a few months before his death — encapsulate the anxieties, claims and counterclaims that still surround the conception, design and building of the first general-purpose electronic digital computer.

And it is Mauchly who is said by some to have studied the work of Dr. John Atanasoff (see related story) before beginning his historic efforts toward the Electronic Numerical Integrator and Calculator (Eniac).

Indeed, Minneapolis District Court Judge Earl Larson ruled in 1973 (Honeywell, Inc. vs. Sperry Rand Corp. & Illinois Scientific Developments, Inc.) that "Eckert and Mauchly did not themselves first invent the automatic electronic digital computer, but instead derived that subject matter from one Dr. John Vincent Atanasoff."

The judge also found, however, according to Eckert, "The application for the Eniac patent was filed by Mauchly and Eckert, whom I find to be the inventors. Of the 17 claims of the Eniac patent at issue in this court, Honeywell has failed to prove the readability of claims 8, 9, 36, 52, 55, 56, 57, 65, 69, . . . or any of them on Atanasoff's machine or any of the work of Atanasoff."

In spite of the seemingly contradictory ruling and whatever the truth, it is Eckert and Mauchly who are generally accorded the honors and awards given inventors, while Atanasoff remains almost entirely out of the spotlight.

John William Mauchly was born in Cincinnati, Ohio, on Aug. 30, 1907. As a young boy, he wanted to be a street car conductor, then a fireman. By high school, he expected to become an engineer.

Mauchly won a state scholarship to the electrical engineering college of Johns Hopkins University, but found after two years that his natural inclination followed that of his father: Physics was his real interest.

The university advanced the outstanding Mauchly in his sophomore year into the doctoral program in physics, which he completed in 1932. After receiving his Ph.D., Mauchly worked at Johns Hopkins for a year as a research assistant, then became head of the Physics Department at Ursinus College in Collegeville, Pa.

Mauchly was a favorite among the students as much for his sense of humor as for his dynamic teaching methods. "Ursinus insisted on teaching the day before Christmas," Eckert recounted.

In a stratagem designed to get around the problem without openly defying the dean of the college, Mauchly "started the lecture, yawned a few times, sat down next to the rostrum, put his elbow on the desk, started talking more and more slowly and finally fell asleep in mid-sentence," Eckert said.

Some student confederates in the class got the rest of the group to tiptoe out of the room, completely convinced Mauchly's "Professor Ho-Hum" act was real, Eckert explained. Mauchly taught at Ursinus from 1933 to 1941, during which time his scientific work centered on weather science, an area that called for long, tedious calculations. Hoping to develop a small, cheap computing device, Mauchly began experimenting with ways of counting electronically and reportedly conceived of an electronic calculating device that would utilize vacuum tubes.

In 1941, Mauchly enrolled in the eight-week defense course in electronics at the Moore School of the University of Pennsylvania — where he met Eckert — and stayed on as an instructor.

# J.V. Atanasoff: Early Efforts

John Vincent Atanasoff, said by some to have directly inspired John Mauchly's work on the Eniac computer, was born in 1903, the son of a Bulgarian immigrant who had worked his way through Colgate University and became an electrical engineer.

His mother was a school teacher with a natural ability in mathematics, which she passed on to her precocious son. When John was nine, he learned to use his father's slide rule and studied trigonometry, calculus, radio theory and physics.

In the early 1930s, Atanasoff taught at Iowa State College in Ames, Iowa, after earning his Ph.D. in theoretical physics from the University of Wisconsin. While teaching, Atanasoff was faced with the same problem that inspired other mathematicians and scientists to contemplate a method of automatic calculation: Most of the problems put to his students required the solution of linear algebraic equations with many variables.

With some knowledge of Babbage and Pascal, Atanasoff began an extensive study of the possibilities of computing technology. "I commenced to go into torture," Atanasoff explained. "For the next two years my life was hard. I thought and thought about this."

Finally, in a dramatic sequence, Atanasoff was inspired with the answers to his questions, according to his expert witness testimony in the Honeywell, Inc. vs. Sperry Rand Corp. & Illinois Scientific Developments, Inc. case.

"One night in the winter of 1937, my whole body was in torment from trying to solve the problems of the machine," Atanasoff testified. "I got in my car and drove at high speeds for a long while so I could control my emotions."

Although Atanasoff usually drove in such a way "for a few miles," that night he claimed to have been "excessively tormented" to the point of driving 189 miles nonstop across Iowa, over the Mississippi River and into Illinois.

"I knew I had to quit," Atanasoff said, so he stopped at a tavern and ordered a drink. In the tavern, "things seemed to be good and cool and quiet," he recalled, and there his torment dissipated.

The jumble of thoughts and inspirations that had tormented Atanasoff for two years suddenly crystalized into four definite solutions to the problem of electronic computing.

Atanasoff decided he would incorporate the following into an electronic digital computer: binary code, nonratcheting logic, serial calculation and regenerative memory.

There followed "many months" during which Atanasoff perfected the ideas he had conceived in the roadhouse in Illinois, including devising his previously nonexistent type of logic, he recalled in a recent interview.

**Research Grant**

Applying to the Iowa State Research Council in early 1939 for money to build his computer, Atanasoff received an initial grant of $650, which bought him the part-time assistance of an engineering graduate student, Clifford Berry, as well as materials to build a "breadboard" model.

When the breadboard model was finished in the fall of 1939, Atanasoff and Berry received two more grants from the school, bringing the total to $1,500. In late 1940, another $6,500 was acquired from a private foundation.

It was in December 1940 that Atanasoff met Mauchly, at a meeting of the American Association for the Advancement of Science. Atanasoff told Mauchly about his computing machine and invited Mauchly to see it.

In June 1941, Mauchly spent five days as Atanasoff's house guest, during which time they discussed and observed the Atanasoff-Berry Computer (ABC). Mauchly also read and made notes on the complete description of the machine, although he did not take the written description with him when he left.

At the time of Mauchly's visit, Berry was working on a binary card punch and reader for input/output and slow memory. Later, the ABC was capable of solving up to 29 simultaneous equations with 29 variables.

Late in 1942, Atanasoff and Berry left Iowa State. Berry took a job with Consolidated Engineering in Pasadena, Calif., and Atanasoff accepted a research position with the Naval Ordnance Laboratory in Washington, D.C., where he becomes the head of the Acoustics Division.

Atanasoff was disappointed that Iowa State College did not apply for a patent on his ABC, which it had promised to do, but he was "well aware" that such a patent would not make him financially independent, he said recently.

It was the Eniac patents case that inspired District Court Judge Earl Larson to find in 1973 that it was Atanasoff who actually invented the concept of the "automatic digital computer."

After that ruling, Mauchly maintained that the ABC was "just a crude little machine that wouldn't really do anything" and that Eniac was "a highly sophisticated and operational machine."

Furthermore, Mauchly reportedly commented, "Eckert and I wish that the Sperry Rand people would have appealed this because it does leave us in a bad position because of the misunderstanding of the court."

But Sperry did not appeal the decision, a point that Atanasoff feels proves the validity of his claims. In view of the continuing controversy surrounding the issue, however, Atanasoff has "not decided to relive the past," he noted recently, but indicated he will write "a full statement" of his early work on computers.

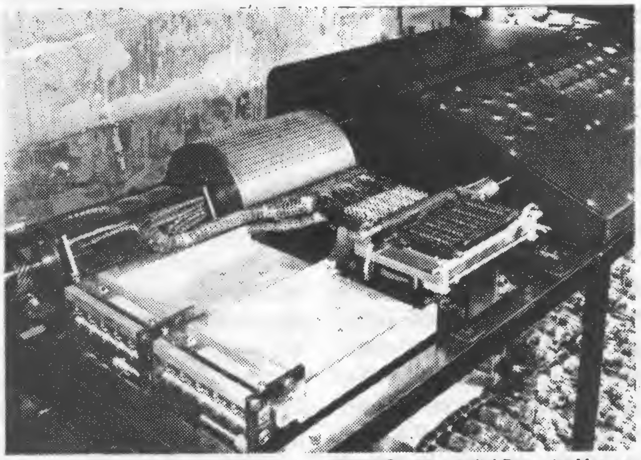
**Business Career**

Besides his inventing work, Atanasoff was a businessman whose firm, Ordnance Engineering Corp., was sold to Aerojet General in 1962. He holds approximately 30 patents.

The awards Atanasoff has received for his work in computing include the Order of Cyril and Methodius, First Class, Bulgaria's highest honor for scientists, in 1970, and two honorary doctor of science degrees.

Atanasoff lives in a house which he helped design on a farm near Frederick, Md., with his wife and 100-year-old mother.

As for Clifford Berry, his scientific promise was not to be fully realized. In 1963 he was found dead in bed with a plastic bag over his head. His death was ruled a suicide.



Courtesy Digital Computer Museum

**The Atanasoff-Berry Computer, 1942. The computer was dismantled and only the drum preserved.**

# Part 11... Capt. Grace M. Hopper & The Genesis Of Programming Languages

*"Almost the first day I met a computer [in 1944], I met Babbage. Commander Aiken had a copy of Babbage's book, and at intervals advised us to read sections of it. I did not meet Lovelace's work until 10 or 15 years later."*

— Capt. Grace Murray Hopper

A century after Charles Babbage's premature struggle to build an automatic computing machine [Part 3], Lt. Grace Hopper learned to program the first large-scale digital computer, Harvard's Mark I — the conceptual realization of Babbage's dream.

In so doing, U.S. Navy Lt. Hopper became as much a computer pioneer as Charles Babbage or Ada Lovelace — and one of the driving forces behind the development of programming languages, specifically Cobol.

Grace Brewster Murray was born Dec. 9, 1906 in New York City, the oldest child of an insurance broker and his wife. "My mother loved mathematics; she had always been interested in it," Hopper said during a recent interview.

The daughter of the senior civil engineer for the City of New York, Hopper's mother "used to go with her father surveying upper New York City — he laid out all the streets," Hopper said, by way of noting that "all three of us [children] were good in math."

### Happy Childhood

A noteworthy event in Hopper's life occurred at the age of four. It was in May 1910 that Halley's comet last appeared, four times as big and bright as the full moon. "My father held me up to look out the kitchen window to see Halley's comet and I was so impressed," Hopper said. "He said I'd see it again and I will." Halley's comet will reappear in 1986.

Recalling her childhood as "very happy," Hopper nevertheless noted that as the oldest, she "got the brunt of everything." On one occasion, she recounted, "a bunch of cousins" and she were caught scrambling around in a pine tree. "Since I was at the top," Hopper said, "it was obvious who started it."

A deep source of happiness for Hopper was the summers she and her family spent in Wolfeboro, N.H., where, in fact, she met her husband, Vincent Foster Hopper, who also summered there from New York.

And a deep source of satisfaction was Hopper's early education in private schools. Considered "normal for those days," Hopper's early schooling was strict by today's standards. "We had to pass tests to prove we could read, write plain English and spell," she recalled.

"Each summer we had to read 20

CW Photo by M. Zientara

books and write reports on them," she added. "You were educated and had some background when you were through then, not like today," Hopper said, noting, "It didn't give us any inhibitions, it gave us an interest in reading and history."

Hopper's education continued at Vassar College, from which she graduated in 1928, with Phi Beta Kappa membership and a Vassar College Fellowship. She then attended Yale University, where she received an M.A. in 1930, the year of her marriage to Vincent Hopper.

In 1934 she received a Ph.D. from Yale, which elected her to Sigma Xi and awarded her two Sterling Scholarships. Hopper's academic awards were just the first wave of honors in a lifetime that has been filled with accomplishments and their prizes and awards.

**Teaching Positions**

From 1931 to 1943, Hopper also taught at Vassar in the Department of Mathematics, rising from an instructor to assistant professor and finally associate professor. During this period she received a Vassar Faculty Fellowship and studied at New York University in 1941-42.

In 1943, Hopper was an assistant professor of mathematics at Barnard College, after which she enlisted in the United States Naval Reserve and attended the USNR Midshipman's School-W in Northampton, Mass.

Why did she join the Navy? "There was a war on!" she exclaimed, explaining, "It was not unusual for a woman at that time to join the Navy; there were 30,000 to 40,000 women there at the time."

After World War II, however, she observed, "They all got married and went home. They walked out and now they're demanding the jobs they walked out on."

As for Hopper, fate withdrew her option to go home after the war; her husband was lost in the conflict in 1945. With no children to care for, and plenty of inspiration, Hopper by then was "all tangled up with computers and the Navy" and continued full steam ahead with her career.

Upon graduating from the midshipman's school, Hopper had been commissioned lieutenant (JG) and ordered to the Bureau of Ordnance Computation Project at Harvard University, where she helped "tame the monster," Howard Aiken's Mark I computer [Part 7].

Largely financed by a $500,000 gift from IBM President Thomas Watson Sr., Mark I was a near-casualty of the war before it was even begun. Fortunately for computing, however, the Navy, in which Aiken was also a lieutenant, realized the value of the device to naval problems and Aiken was released on detachment to complete the work.

It was at Harvard that Hopper learned to program the beast. In 1946, she resigned from her leave of absence from Vassar and joined the Harvard faculty as a research fellow in engineering sciences and applied physics at the Computation Laboratory.

**Birth of Debug**

It was also there that the term "debug" came into being, according to Hopper. "In 1945, while working in a World War I-vintage non-air-conditioned building on a hot, humid summer day, the computer stopped. We searched for the problem and found a failing relay — one of the big signal relays," she recalled.

"Inside, we found a moth that had been beaten to death. We pulled it out with tweezers and taped it to the log book," Hopper continued. "From then on, when the officer came in to ask if we were accomplishing anything, we told him we were 'debugging' the computer."

Hopper worked on applications programming for the Mark I, Mark II and Mark III computers at Harvard for the Navy and in 1946 was presented the Naval Ordnance Development Award.

After her three years of work on Naval computers, Hopper joined the Eckert-Mauchly Computer Corp. in Philadelphia [Part 10] in 1949 as senior mathematician. Thus began a long association that ended with her retirement from the group in 1971.

When Hopper joined the Eckert-Mauchly Computer Corp., it was building the historic Univac I, the first large-scale commercial electronic digital computer, which was eventually installed at the U.S. Census Bureau in 1951. Thus Hopper began her fourth pioneering effort in programming techniques.

She remained with the company as a senior programmer when it was bought by Remington Rand in 1950, and through its merger in 1955 with Sperry Corp. to form Sperry Rand.

It was in 1952 that Hopper published the first paper on compilers, leading to her appointment as systems engineer, director of automatic programming in the Univac Division of Sperry Rand Corp.

The first computers had necessarily been programmed in full detail, including at times the specification of individual bit patterns when no shortcut had been developed.

It soon became obvious that many programs, even though different in total objective and results, used shorter sets of instructions (subprograms, routines and subroutines) that were logically identical and interchangeable in different jobs or parts of the same job.

Such instruction routines could involve solving certain classes of equations, extracting roots, arranging data within memory or for printout or for classifying and sorting. Therefore, the idea of libraries of subroutines became urgent and economically necessary to eliminate errors, cut tedium and minimize duplication of effort.

**Automatic Programming**

In the earliest significant steps toward software development, the computer itself assisted in program preparation. In "automatic programming," the computer provided, first, symbols or mnemonics as instruction names and then, increasingly, other symbols as designations for more sophisticated capabilities.

Thus, computer programs called "interpreters" transformed the mnemonics into actual binary codes that the computer could accept and execute. Hopper gives great credit to Dr. John Mauchly for his development of the Short Order Code interpreter.

Also noteworthy was Frances E. (Betty) Holberton's Sort Generator, the first program that wrote a program, Hopper explained, adding, "Betty taught me to draw flow charts. It's too bad we've moved away from them because we need to know the structure of our systems." Holberton is currently a mathematician in the area of Fortran standards for the National Bureau of Standards.

As for compilers, they accept symbols representing more complex operations and compile sets of such pretested routines. In describing her work on compilers, Hopper recalled how programmers were constantly required to copy coding from notebooks into other notebooks.

Speaking slightly tougue-in-cheek at Pioneer Day at the National Computer Conference 1981, Hopper claimed, "Programmers cannot copy things," and furthermore, "programmers cannot add."

"So we had to let the computer do it," Hopper said, noting that the result was the A-O compiler.

An important early activity that began to make such techniques pay off was one in which Hopper was the premier pioneer. She energetically encouraged the creation of groups of users of common equipment to share their contributions toward the establishment of permanent subroutine libraries.

The largest such group is the IBM "Share" organization. The Association for Computing Machinery also maintains libraries of subroutines and provides a communications medium for identification, publication and exchange of algorithms and programs.

Hopper's compiler paper in 1952 was the first of more than 50 she has published on software and programming languages. Her deep interest in applications programming led her to the Defense Department-sponsored Committee on Data Systems Languages (Codasyl) in 1959.

Held at the Pentagon to consider the establishment of a language particularly suited to business data processing activities, the committee meeting included representatives from private and government users as well as from computer manufacturers.

Within Codasyl, Hopper was instrumental in the development of the Common Business-Oriented Language (Cobol). By September 1959, Codasyl had specified a language it considered superior to existing language-compiler systems.

The language specification was further modified and by December 1959, Cobol existed as a language that was not identified with any manufacturer and therefore presented advantages for both government and private industry. Since then, of course, hundreds of other, more specialized application languages have been created.

Throughout the '50s, '60s and '70s, Capt. Hopper remained a prime mover in the development of Cobol and has worked tirelessly to test various Cobol compilers.

### Standardization Role

She has served on the American National Standards Institute (Ansi) X3.4 Committee on the standardization of computer languages and presently serves on the Codasyl Executive Committee.

Her work on standardization notwithstanding, Hopper believes standards have been neglected. "By not adopting — or following — standards, the federal government spends $450 million a year converting computer programs," she observed. "A real waste of money."

Since 1959, Hopper has been associated with the Moore School of Electrical Engineering of the University of Pennsylvania, first as visiting lecturer; in 1962 as visiting assistant professor; in 1963 as visiting associate professor; and since 1973 as adjunct professor of engineering. In 1971 she was appointed professorial lecturer in management science at George Washington University, in Washington, D.C.

### Fellowships and Awards

In 1962, she was elected a fellow of the Institute of Electrical and Electronics Engineers (IEEE), and in 1964, she received the Achievement Award from the Society of Women Engineers.

In 1969, the Data Processing Management Association (DPMA) selected Hopper as its first Computer Sciences Man of the Year. The American Federation of Information Processing Societies (Afips) gave her the Harry Goode Memorial Award in 1970.

The year 1971 brought a slight switch and a great honor when the Univac Division of Sperry Rand established the Grace Murray Hopper Award for young computer professionals, now awarded annually by ACM.

In 1972, she received an honorary degree from the Newark College of Engineering, the Wilbur Lucius Cross Medal from Yale University and was made a fellow of the Association of Computer Programmers and Analysts.

In 1973, Hopper received an honorary degree from the C.W. Post College of Long Island University, was elected to the National Academy of Engineering, received the Legion of Merit from the Navy and became a distinguished fellow of the British Computer Society.

The following year saw Hopper receive the honorary degree, Doctor of Laws, from the University of Pennsylvania at the 50th anniversary convocation honoring the Moore School.

In 1976, she received the Distinguished Member Award of the Washington, D.C., Chapter of ACM and an honorary degree from Pratt Institute. 1979 was the year Hopper got the W. Wallace McDowell Award from IEEE and in 1980, she received honorary degrees from Linkoping University, Sweden and Bucknell University.

She is a fellow of the American Association for the Advancement of Science and a member of the Franklin Institute, the U.S. Naval Institute and the International Oceanographic Foundation.

### Navy Connection

She maintained a close connection with the Naval Reserve and was successively promoted to lieutenant, lieutenant commander and commander. At the end of 1966, she was retired with the rank of commander in the Retired Reserve.

She was recalled to active duty on Aug. 1, 1967. In 1973, she was promoted to captain on the retired list of the Naval Reserve. She is presently serving on active duty with the Naval Data Automation Command.

A popular and energetic lecturer, Hopper is almost constantly on the road, except for "every Friday night, when I wash my white hat top, white shirt and white hair."

After her 40 years in computing, Hopper is fond of noting, "The computer industry today is about where the Model T was when it was developed. When I was a child, Henry Ford came along and invented a car everyone could have — as long as they wanted it black.

"That's where we are today," she said. "At the very beginning of mass use of the computer. We haven't even begun to exploit its potential."

Part of its potential, which Hopper feels is in great need of exploitation, lies in predicting weather patterns, managing energy resources and increasing agricultural output.

After four decades of pioneering work, awards, honorary degrees and "opportunities I never could have dreamed of," Hopper feels her greatest contribution has been "all the young people I've trained."

She feels strongly that "lots of bright youngsters aren't hampered by 'we've always done it this way,' 'it won't work' or 'I've never heard of it.' "

# Part 12 . . . What's Past Is Prologue: A Glimpse Into the Future

*'In walking the thin line between innovation and hubris, will man overstep his bounds in an attempt to create a machine too like the human brain? Will we try to manufacture an amoeba, or an "emotional" robot or an android superior to us in every way?*

*And will we succeed? Such questions plague the minds of those who perhaps know "too much and yet not enough."'*

Speed and miniaturization are still the bywords of computer development.

From the very beginning of the history of calculation — through abacus, the mechanical calculator, electromechanical relay devices, vacuum tube technology, the transistor and the microprocessor chip — progress has been toward faster and more reliable technologies.

While Howard Aiken's Harvard Mark I computer [Part 7] in 1944 took about five seconds to multiply two 10-digit numbers, Eckert and Mauchly's Eniac computer [Part 10], only two years later, multiplied 500 pairs of 10-digit numbers per second. Today, the Cray Research, Inc. Cray-1 scientific computer can multiply 240 million pairs of 16-digit numbers per second. And the Cray-2 — scheduled to be released in 1984-85 — is expected to multiply up to 2.8 billion pairs of 16-digit numbers per second.

Size, too, remains a concern of computer scientists. Since the room-sized Mark I and Eniac computers were built, the machines have steadily shrunk to the point where scientists foresee within a few years a computer the size of the human brain, but with speeds 100 or more times faster than the Cray-1.

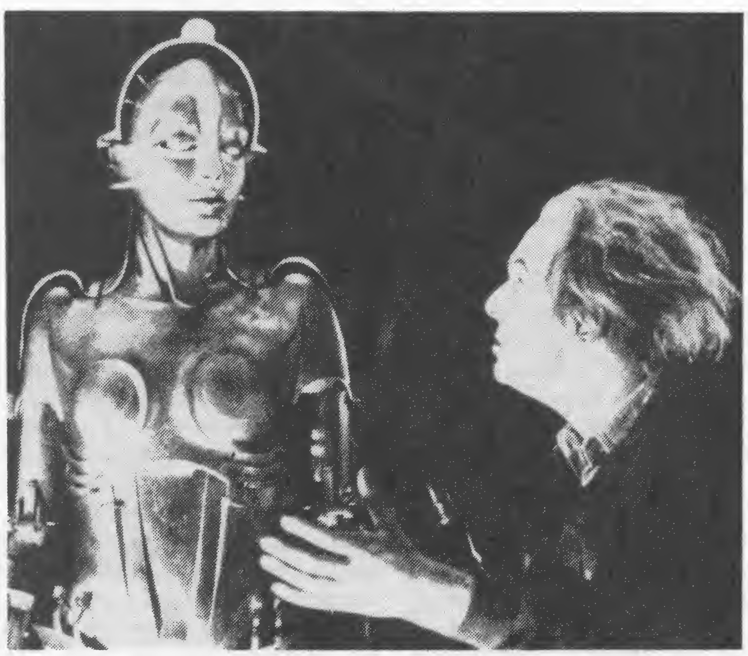
Speed and size have always been, and today remain, intrinsically linked in the technology of the moment. Major advances in speed have historically been because of the development of faster switches. While the Mark I's relays could switch in a few thousandths of a second and Eniac's smaller tubes switched in a millionth of a second, modern fingernail-size chips can do the same in only a few billionths of a second.

Electrical signals can travel through a circuit at roughly half the speed of light, or six inches in a billionth of a second. Scientists have packed switches closer and closer together to cut the distance the signal must travel, trying to create progressively faster computing speeds.

Unfortunately, such dense packing can cause components to melt from the heat generated by electrical signals. With switching devices continually shrinking in size, the barrier to faster computing times — instead of stemming from the speed of the switches themselves — can now be traced to the distance between switches.

Future systems will have to incorporate new switching technology — possibly modeled after the revolutionary Josephson junction now in development — to surmount this problem.

The Josephson junction is a switch that generates only microwatts of heat — thousands of times less than high-speed transistor circuits. This allows them to be packed extremely



Courtesy Universum Film Aktiengesellschaft; Academy of Motion Picture Arts and Sciences

**A vision of the future? From Fritz Lang's 1927 film "Metropolis," in which the scientist Rotwang creates a robot worker in the image of the heroine, Maria.**

closely together, thus solving the problem of distance between switches.

The switch is based on the property of superconductivity, the total loss of resistance to electric current flow in many substances at temperatures near absolute zero.

While modern chips now switch in a few billionths of a second, Josephson logic circuits — expected to be available in the 1990s — would be capable of switching in 50- to 100 trillionths of a second (picoseconds).

In computers based on the Josephson technology, six inches traveled in a billionth of a second would actually amount to 10 times the calculation rate of today's fastest machines and 25 times the speed of today's general-purpose computers, because so many more switches would be crammed into those six inches.

Scientists envision a compact unit of electronic components the size of a coffee can suspended in a bath of liquid helium at 4.2 degrees above absolute zero, or -452 degrees F. A maze of tiny wires would transport power and data in and results out. Inside, millions of minute Josephson junctions would perform billions of mathematical operations every second.

Another innovative cooling technology will make the scene with the Cray-2, in which the computer's entire circuitry will be immersed in an inert fluorocarbon liquid developed by the 3M Corp. back in the days of World War II.

Although the liquid did not prove useful for much of anything four decades ago, its complete lack of electrical properties promises it a home in the computer technology of tomorrow. While it will only cool the circuitry — as opposed to the Josephson junction's "supercooling" effect — the liquid is said to guarantee perfect heat dissipation.

The resulting close packing of computer components will allow the Cray-2 to feature a maximum 16-in. wire length, versus the 3-ft length in the Cray-1 or 6-ft to 12-ft in current commercial computers. The Cray-2's switching speeds would reportedly be only slightly slower than the Josephson junction's.

One of the potential benefits of such technology is the fact that, unlike the Josephson junction, the Cray-2 would not require a tightly sealed box to protect its liquid. Therefore, while the Josephson junction would be largely inaccessible, the Cray-2 would be quite easily maintained and would not require as much special equipment for use.

Are we fast approaching the ultimate in miniaturization? Scientists think not, observing as they have the staggering amounts of data contained in a single DNA molecule, for example, or in one-celled animals and plants visible only under a microscope. "Even the amoeba is a far smaller and far more powerful information processor than today's best chips," one observed.

### Future Applications

But is all this staggering progress really necessary? Don't computers do things fast enough already? Not in such areas as long-range weather prediction, which directly affects crop management and therefore the world's food supply; and not in space surveillance, where satellites have generated immense amounts of data that simply take too long to digest.

In the Landsat program, for example, existing supercomputers are even finding it a challenge to handle the large amounts of processing required. Data rates are so fast and the processing so significant that currently we have only "band-aid solutions," according to observers.

Another area in need of the speeds of supercomputers is oil exploration, in which oil companies can model oil reservoirs before drilling in order to best determine how to extract the "liquid gold."

Arco, Exxon and Shell Oil (UK) have all installed Cray supercomputers and Chevron will be installing one in February 1982. According to one oil company analyst, computer modeling of one company's share of the Alaskan oil field can result in increasing total oil production by a minimum of 1% to 2%.

"With an estimated total value of $100 billion, that translates to direct added revenues of $2 billion," he noted, comparing the savings to the $10 million supercomputer price tag.

Within the computer industry, supercomputers are edging into the design and development of memory chips, where the mark of success is fast becoming not the complexity of chip design, but rather the speed with which a developer can get a new design to the marketplace.

Supercomputers can help chip makers to simulate and analyze chip designs so they do not actually have to be built. The only chip developer so far to use a supercomputer for the task is Bell Laboratories, which is reportedly feeling dramatic advantages from reductions in chip development time from six months to two or three weeks.

Another nascent supercomputer market is structural design and analysis in such industries as automobile and airplane manufacturing. Simulation tests can reduce the number of prototypes that have to be built, thus saving time and untold millions of dollars in production costs.

A possible future application of supercomputers is business strategic forecasting, wherein the turnaround time on a complex model could be reduced from two hours on an IBM 3033 to five minutes on a supercomputer, one analyst estimated.

But in walking the thin line between innovation and hubris, will man overstep his bounds in an attempt to create a machine too much like the human brain? Will we try to manufacture an amoeba, or an "emotional" robot or an android superior to us in every way? And will we succeed?

Such questions plague the minds of those who perhaps know "too much and yet not enough," according to the scientists. "There's nothing in principle that I would seriously believe we can't do," said Roger Schank, director of Yale University's Artificial Intelligence Laboratory.

"The only one is this emotions issue," he noted, explaining, "We probably won't be able to give these things emotions, though we'll be able to have them act as if they have emotions."

Now the question is, do we want something around "acting as if" it has emotions? Isn't that the worst kind of chicanery? Or would it be a real comfort to the growing numbers of people who will spend their days working with machines? Would it break up the tedium or would it be an insult to human intelligence and sensitivity?

Humans being what they are, the answers to such queries undoubtedly will depend on the human and machine involved in any one situation. In any event, it would be wise to examine just how far we have gone in developing artificial intelligence and what we may expect in the future.

Artificial intelligence (AI) is an examination of the way humans perceive and assimilate data, reason abstractly, adapt and communicate in an effort to produce such behavior in computers. Although the formal discipline is a new one, questions regarding the nature of intelligence were being asked 50 years ago by such computing pioneers as Alan Turing [Part 8], Norbert Wiener [Parts 4 and 8] and John Von Neumann [Part 10].

As of now, the useful development of AI centers almost exclusively around computer-controlled industrial robots and the acknowledged worldwide leader in the field is Japan.

Typical of the Japanese robotic environment is an engine factory in a suburb north of Tokyo that employs a small crew of human workers during the day, at the end of which robots take over the work and toil tirelessly throughout the night under the supervision of a lone human overseer.

The Japanese have also moved quickly in the area of automated semiconductor production. They have automated the bonding process — attaching fine gold wires to integrated circuit chips — while the U.S. continues to have the task done in Southeast Asia by assembly workers.

The result? Japanese companies have achieved better quality and reliability and higher yields, allowing them to claim a significant share of the world semiconductor market.

Furthermore, last January, Fujitsu Fanuc opened a $38 million plant that utilizes robots and numerically controlled machine tools to manufacture other robots and automated equipment. This year the plant will employ 100 workers to produce approximately 100 robots each month — about one-fifth the number of workers needed to do the same job in a conventional plant.

Like the engine factory, the Fujitsu plant operates 24 hours a day, with human workers assigned to assemble the parts the robots have made during the night. By 1985, Fujitsu hopes to have its elf-like robots performing assembly tasks as well.

The Japanese reportedly are also developing a new generation of robots expected to be able to handle objects with great precision. Nippon Electric has an in-house robot named Arms-D, said to operate at micrometer-level tolerances.

Nippon Electric claims that the Arms-D technology could ultimately cut the electronics factory work force in half, because it would be more economical to produce many kinds of products in small amounts. Arms-D reportedly will be commercially available in several years.

In the U.S., car and farm- and truck-equipment manufacturers have pushed hard in the last year to make some progress in robotics. Rising labor costs and foreign competition convinced these manufacturers to pour millions into retooling factories and installing robots on assembly lines for welding and parts selection. Automakers are also using robots to paint and to move equipment around their warehouses.

"A robot can perform the functions of two people," according to Mark Cocroft of General Motors Corp., which expects to have 14,000 to 15,000 robots by 1990. GM's current robot population, including those on order, stands at 1,000.

Chrysler Corp. spent $75 million retooling for robots in its K-Car plants last summer and now has about 220 robots in three plants. Ford Motor Co., now with 246 robots, expects to double that population by 1984. Ford and GM both use robots for numerically controlled painting projects, as well as for emission checking and the thankless tasks of loading/unloading and stacking/unstacking goods and pallets.

At the Springfield, Ill., body plant of International Harvester, 52 robots spot-weld tractors and truck bodies. Two robots perform heavy press loading at the firm's Louisville, Ky., plant and in Cincinnati, axles are forged by robots.

While microprocessors control smaller robotic movements, most of the robots used by the auto and farm equipment manufacturers are run by minicomputers and even mainframes. John Deere uses a Digital Equipment Corp. PDP-11/44 and an IBM 370 for nearly all its factory operations, including bookkeeping and payroll.

A significant breakthrough in robotics recently came from Machine Intelligence Corp. (MIC) in a development that promises to revolutionize the manufacturing process. The breakthrough is a first step toward the solution of what AI researchers call "the vision problem."

After years of research at such academic institutions as Stanford University, Carnegie Mellon Institute and SRI International, a nonprofit research institute, MIC has made commercially available a so-called "hand-eye system," allowing robots to "see" and differentiate objects from one another.

The vision system looks at black-and-white images on a high-contrast scene. By analyzing them in two dimensions, the system can reportedly identify and sort objects of mixed types. The system is said to be usable for materials handling as well as assembly tasks.

Teaching the system, which is controlled by a DEC LSI-11, is simple. "You show it that this is a widget and this is a gadget," explained Earl Sacerdoti, MIC's director of research. "You show it to it five or six times in different positions with different fields of view and then it 'knows' it.

Whatever the uses or users, the benefits of robotics are uniform and clear: Improved quality, efficiency, precision and consistency are cited again and again by those who have taken the plunge.

That, of course, is the view from the top of the corporate ladder. What about the thousands of workers whose jobs will necessarily be eliminated by robots?

The issue has not been totally ignored, according to GM's Cocroft, who predicted that attrition would take care of some of the job loss, while some workers will be retrained to perform robot and computer maintenance.

No one can promise that displaced workers will be taken care of — one way or another — but history has shown that a new technology somehow eventually manages to blend into the fabric of existence, resulting in irrevocable changes, both good and bad, that are impossible to stop. The attempt would be foolhardy.

Of no consolation at all to victims of technological progress will be the fact the machines over which they watch, or which have replaced them, are actually extremely stupid.

However, at least that knowledge may help dispel the image of the superior robot in human form, ready to control the controller and perhaps even the entire world. As Sacerdoti is fond of telling his lecture audiences, "Look — computers are really stupid. If we can make a computer as smart as a chicken, it will be much more useful than what we have today."

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